

Lunar Reconnaissance Orbiter: (LROC)

Audience

Grades 5-9

Time Recommended

Two 60-minute sessions

AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.
- 12D/M10: Understand oral, written, or visual presentations that incorporate circle charts, bar and line graphs, two-way data tables, diagrams, and symbols.

NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

- c. Use appropriate tools to gather, analyze and interpret data.
- d. Develop descriptions and explanations using evidence.
- e. Think critically and logically to make relationships between evidence and explanations

Content Standard D (5-8): Earth and Space Science; Earth's History:

- a. The Earth processes we see today, including erosion, movement of lithospheric composition, are similar to those that occurred in the past.

Content Standard E (5-8): Science and Technology:

- b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

MATERIALS

- Feature ID Charts
- LROC-WAC Equatorial Mosaic
- Wet-erase markers
- LROC-WAC Maps
- Student Data Log/ rulers
- Set of task worksheets for each student
- Index cards

Lunar Image Analysis: Revealing the Geologic History Through Mapping

Learning Objectives:

- Differentiate between everyday and scientific observations.
- Generate the series of geologic events that occurred in a region of the Moon.
- Integrate new understanding of a Moon-related topic through scientific observations.
- Collaborate and communicate results through identification.

Overview: In this activity, students step into the shoes of real planetary scientists and experience one of the first steps in the process of science — making observations. Students will be tasked with identifying lunar features and determining the geologic history of the area.

Preparation:

1. Before starting the first activity, take time to give the students a brief introduction of the Lunar Reconnaissance Orbiter (LRO) mission and Lunar Reconnaissance Orbiter Camera (LROC) using the background Information below. You can have students read these pages or present the data using slides, videos and images, which can be downloaded from NASA's LRO website (<http://lunar.gsfc.nasa.gov>) and LROC's specific website (<http://lroc.sese.asu.edu>).
2. Read the procedure section thoroughly so as to understand the overall progression of each lesson. Review the student worksheets at the end of the lesson and decide how you will use each one.

Background Information:

NASA RETURNS TO THE MOON WITH LRO:

At the core of NASA's future in space exploration is the return to the Moon. Once there, we will build a sustainable long-term human presence with new spacecraft, robotics and life-sustaining technologies. The Lunar Reconnaissance Orbiter (LRO) is an unmanned mission to create a comprehensive atlas of the Moon's features, search for safe and interesting landing sites, identify important lunar resources, and characterize how the lunar radiation environment will affect humans.



Lunar Reconnaissance Orbiter

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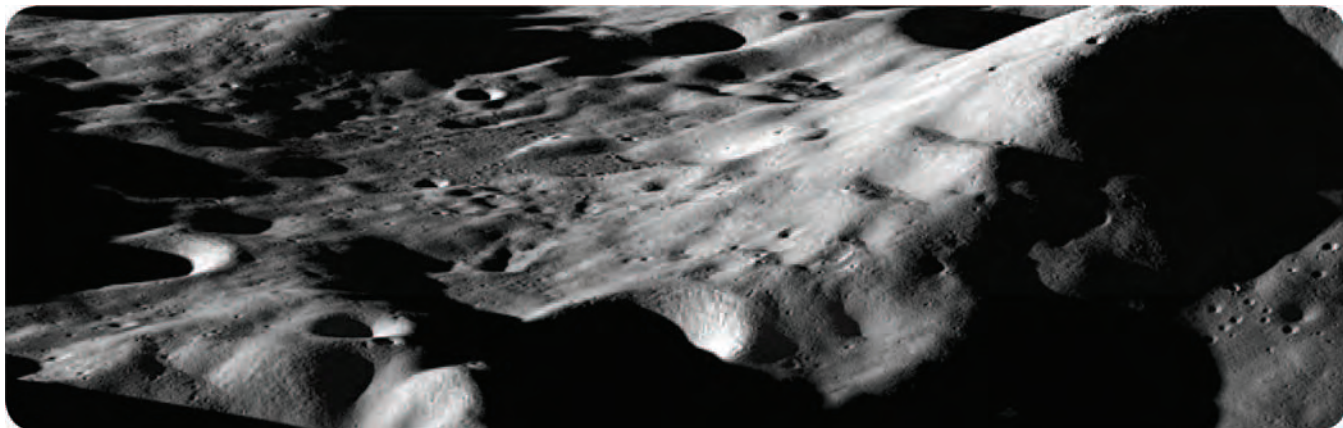


Image: taken by the Lunar Reconnaissance Orbiter Camera facing from the northeast across the north rim of Cabeus crater as the spacecraft rolled 70° to the side. Foreground is about 10 km wide. Credit: NASA/GSFC/ASU.

Procedure:

(5E APPLICATION)

ENGAGE:

Warm-up: What can you tell from a picture?

1. Display the landscape picture for all students. Students should make observations of the image. What are they certain of based on the photo? Can they tell where the photo was taken?
2. Give students approximately 5 minutes to observe, then discuss as a group.
3. Now, ask students what information is missing? If we had to pick an exact location where this image was taken, what else would we need to do that? (Students should say they need more observations, more distinguishing characteristics, or possibly a wider-angle view to see the area around.)
4. Make reference to the fact that images provide the simplest means of exploring another world. We use images of the Moon to make observations and identify what other information we need. We zoom in and zoom out to get better detail or more information about our image. Let's look at some of these Lunar images.

EXPLORE:

Tasks 1 and 2: Identify Surface Features

(Hand out Feature ID Charts, Sunlight and Shadows sheet, dry-erase markers, and Student Data Log; see Teacher Resource #1 and #2 for an orientation of these materials in the supplemental materials section)

1. Before distributing materials, have students brainstorm analogous features they know exist on Earth that may also exist on the Moon. This will help students build knowledge and make connections to prior knowledge throughout the activity.
2. Familiarize and distribute Feature ID Charts, Sunlight and Shadows sheet, and LROC WAC Equatorial Mosaic images to students.
3. Have students use dry-erase markers to identify features on laminated images. Have students initially work with one image.

4. After approximately 10-15 minutes, have students trade images they have analyzed so other students can make observations of other images.
5. End this part of the activity with a discussion of features observed in images.
6. Ask students to record the identified features into the Student Data Log and the geologic processes involved in their creation.

Teacher Tip:

The observations students will make here are most likely considered “everyday observations.” This means they will be simplified to examples such as “There are 30 craters in the image.” While this is a true observation, it most likely will not lead to an experimental question. Providing extra time, even when students appear to be done and off-task, will allow them to make better observations; however students may need more content knowledge about the topic they choose before they can make scientific observations. This will be addressed later in the lesson.

Task 3: Determine the Relative Ages of Features

(Hand out Lunar Crater Classification, Crater Density, and Relative Age Dating Principles sheets— see Teacher Resources #2)

1. Before distributing materials, discuss with students how they may know when one lunar feature is older or younger than another. This discussion will help students build knowledge and make connections to previous knowledge throughout the activity.
2. Familiarize and distribute the Relative Age Dating Principles handout to students.
3. Have students use dry-erase markers to identify relative ages of features on the original image they were working with. Have students at least label the “oldest” and “youngest” features. Students can then identify relative ages of other features.
4. After about 8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of the Moon) as part of their discussion.
5. Ask students to go back to their Student Data Log and include the order of which the features have occurred in the “Relative Age” column and the evidence they used to determine this rank in the Evidence column.

Task 4: Making Measurements

(Hand out rulers and the Student Data Log/ Measurements sheet)

1. Prior to starting this segment, choose a known distance in meters (you can borrow a measuring tape wheel from your track and field coach to measure out the distance ahead of time.)
2. When your class returns, ask them how far they think they walked. Write these numbers on the board. One of the goals of Task 4 will be to help students understand the concept of scale. You will revisit these later.
3. The students will use the directions in Task 4 to make conversions and measurements of their LROC WAC Equatorial Mosaic image and record them on their Student Data Log-Measurement sheet.

EXPLAIN:

Identify Surface Features:

End this part of the activity with a discussion of features observed in images.

Determine the Relative Ages of Features:

After About 8-10 minutes, have students discuss the relative ages of features on their image with other groups. Students should discuss the geologic history (what has happened in their area of the Moon) as part of their discussion.

Making Measurements:

Review the distances of your walk on the board. Ask students which is more likely the correct distance. To get a sense of how large a feature is compare it to the distance they walked. How many times would they need to take that walk to walk all the way across the feature?

ELABORATE:

1. Have students take their list of geologic features they have identified on the Moon and make a list of similar Earth geologic features and their locations.
2. Compare and contrast the geologic features on both planets.
3. Present a hypothesis as to why the geologic features might differ.

EVALUATE:

Identify Surface Features:

Ask students to record the identified features into the Data Log Sheet and the geologic processes involved in their creation.

Determine the Relative Ages of Features:

Ask students to go back to their Student Data Log and include the order of which the features have occurred in the Relative Age column and the evidence they used to determine this rank in the Evidence column.

Tasks 5 and 6: Making Scientific Observations and Establishing a Research Topic

For students to make scientific observations instead of “everyday observations,” they will need to understand a particular topic very well. To do that, they will need to establish a topic that interests them on the Moon and do in-depth research on that topic. Scientific observations lead to testable research questions. A rubric has been provided (located in assessment section) to evaluate the student’s ability to write scientific observations and to actively debate the qualities of a strong research topic.

Establishing a Research Topic:

Materials Needed:

- Task 5 Sheet (Establishing a Research Topic)
 - Background Research Sheets
 - Index cards (3”x5”)
 - Dry-erase Markers
1. Have each student find a partner and work together to fill in list #1 on the Establishing a Research Topic worksheet. They should spend about 3-5 minutes doing this and can come up with topics from any aspect of lunar exploration or geology that interests them.
 2. Encourage Student Discussions!

The image shows two overlapping worksheets from a NASA educational kit. The top worksheet is titled 'TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST' and includes instructions for students to write a general topic and then narrow it down. The bottom worksheet is titled 'Background Research' and features a table with three columns: 'How was the feature formed?', 'Where and how often does it occur on the Moon?', and 'How and why is it different from what can be found on Earth or other planetary surfaces (geological history)?'. The table has three rows for data entry, each with a 'Describe' label in the first column.

3. As a class, the students will need to debate and establish their research topic of interest. Should the class be evenly split on this decision, they could possibly combine the two topics to form a relationship.
4. After the students have established a topic, they will need to do some research about it. The goal is to learn how the lunar features are similar or different to features on Earth or other planetary bodies. They will become experts on their topic. This understanding will help the students make scientific observations in the next activity. For example, their observations will improve from “there are 30 craters in the image” to “there are 5 modified craters, 25 destroyed craters, 10 craters less than 2 km wide, 20 greater than 2 km wide, and all of the modified craters lack a central peak, etc.” Photocopy as many background research sheets you believe they will need.
5. Students may need help getting started with their research, depending how much experience they previously have. Here are a couple of sources they can use to learn more about their topic of interest (print out any information you deem necessary):

- <http://www.lroc.asu.edu/lrolive/#loc=video&category=sci&vid=102>
- <http://www.lpi.usra.edu/lunar/moon101>
- <http://lroc.sese.asu.edu/news/index.php?/categories/2-Featured-Image>
- http://wms.lroc.asu.edu/lroc_browse
- <http://lunar.gsfc.nasa.gov/moonfacts.html>
- <http://lunar.gsfc.nasa.gov/faq.html>
- <http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html>
- http://www.nasa.gov/multimedia/videogallery/index.html?media_id=135568801

Making Scientific Observations:

Now that students have background knowledge on their topic, they should be adequately prepared to make scientific observations about their selected topic, as opposed to everyday observations. It will be important to point out to the students the primary difference between these types of observations is the understanding of the topic. A scientist who understands how craters are formed will notice a crater(s) with a different pattern or shape, or possibly even different features, which are not common to the crater itself. Simply observing that a crater exists is an everyday observation— more must be extracted to prove useful, scientifically speaking.

Choosing a Final Research Topic:

Students should take time to share their most interesting scientific observations. These will guide the potential discussion and will allow them to group topics or concepts. It may be helpful to use index cards for topics and scientific observations. Students may even find they can incorporate a couple of topics of interest for primary and secondary science. Allow students to debate and come to a consensus on the final topic for research. This is an opportunity to experience authentic science and debate. Scientists typically do not work individually, but discuss ideas and interesting topics for research with other scientists in the particular field of study.

Some research topic examples, but are not limited to:

Impacts:

- | | |
|------------------|------------------|
| • impact melt | • terraced walls |
| • central peak | • crater chains |
| • ejecta | • straw field |
| • simple crater | • impact basin |
| • complex crater | • rim |

Choosing a Topic for Research

1. Choose a topic for research. Write the topic in the box below. (Choose one observation to study and write it in the box below.)

Topic: _____

2. Make a class decision about choosing scientific observations. For the major research categories for students, write your topic in the box below. (Choose one observation to study and write it in the box below.)

Observation #1	Observation #2

3. Write a hypothesis about your chosen scientific observations. For the major research categories for students, write your hypothesis in the box below. (Choose one observation to study and write it in the box below.)

Hypothesis: _____

4. Use the data you collect to write a conclusion.

Conclusion: _____



LUNAR IMAGE ANALYSIS

Lesson Overview: For this activity, you will be completing 6 total tasks:

WARM-UP:

Look at the picture and answer the questions.

TASK 1: LOCATING IMAGES ON THE MOON

In this task, you will use the latitude and longitude of the image to find its location on the Moon.

TASK 2: IDENTIFYING LUNAR FEATURES

In this task, you will be using Feature ID Charts to identify geologic features on the LROC-WAC Lunar image.

TASK 3: UNRAVELING THE HISTORY

In this task, you will use Relative Age Dating Principles to create a sequence of events for your LROC-WAC Lunar image.

TASK 4: MAKING MEASUREMENTS

In this task, you will be using a scale bar to determine how large certain features are on the lunar surface.

TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST AND BACKGROUND RESEARCH

In this task, your team will decide on a topic you are all interested in most for conducting research, in order to become an expert in that topic.

TASK 6: MAKING SCIENTIFIC OBSERVATIONS

In this task, you will be making scientific observations on your topic using your new understanding from background research.

KEY WORDS:

- **Scientific Observation:** An observation made using scientific knowledge from background research on the topic.
- **Initial Observation:** Observations that lead to an experimental question.
- **Experimental Observation:** Observations made during data collection. These may change the direction of the research or lead to future experimental questions.
- **Analysis Observation:** Observations made as a result of graphing. These could be interesting data points, such as outliers. Also, these may lead to future experimental questions.
- **Qualitative:** Observations based on a physical characteristic such as color, shape, or texture.
- **Quantitative:** Observations based on numbers, such as number counts or measurements.
- **Bias:** The purposeful or unintentional influence of observations or data that results in an expected answer, instead of a real answer.

WARM-UP: WHAT CAN YOU LEARN FROM A PICTURE?

Name _____

Directions: Look at the picture below and answer the following questions.

1. What do you know for sure from this picture?
2. Can you tell where it was taken?
3. What information is missing?
4. If we had to pick an exact location where this image was taken, what else would we need to do that?



Photo Courtesy of Stefan Seip and NASA Astronomy Picture of the Day

TASK 1: LOCATING IMAGES ON THE MOON

Core Question: How do people reconstruct and date events in Earth's planetary history?

For this activity, you will be acting as a scientist. You will complete four tasks as part of an introduction to the Lunar Reconnaissance Orbiter Camera (LROC) images. Your investigation will include the following:

1. Recording observations of geologic features on the Moon,
2. Discovering what geologic features can be identified on the surface of the Moon, and
3. Determining the surface history of an area (i.e. which features are older, younger, and what has happened in the area to make it look the way it does today).

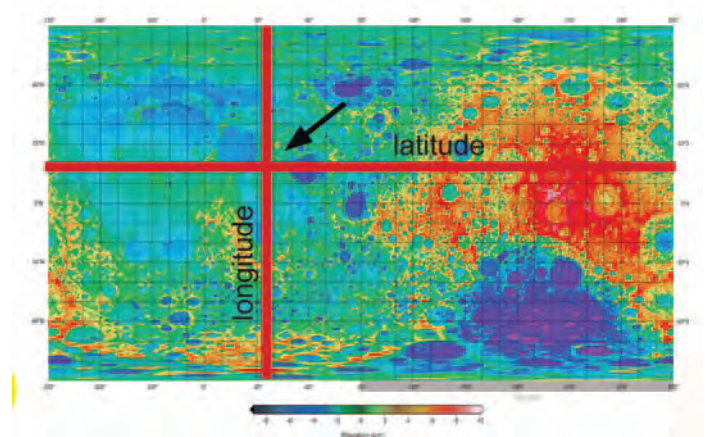
During this activity you will complete a **Student Data Log**. A variety of tools are available to help you in this activity. Your teacher will show you each of these throughout the activity.

In this section, you will learn how to locate **LROC images** on the Moon. To find an image location, you will need to know its latitude and longitude:

- The **longitude** gives the location east of the Moon's **prime meridian** (0°E), which is the line passing through the middle of the Moon as seen from the Earth during a full-moon.
- The **latitude** gives the location north or south of the lunar **equator** (0°N). Both latitude and longitude are given in terms of degrees.

Once you receive materials from your teacher, work with a partner to do the following:

1. Find the **latitude** and **longitude** of your LROC image. The coordinates are printed on your image.
2. Using a dry-erase marker, draw a line across the WAC Topographic Map marking your image's latitude.
3. Now, draw a line across the WAC Topographic Map marking your image's longitude. Your image is located where the lines cross!

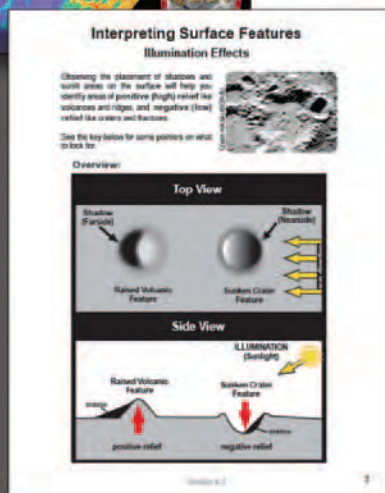
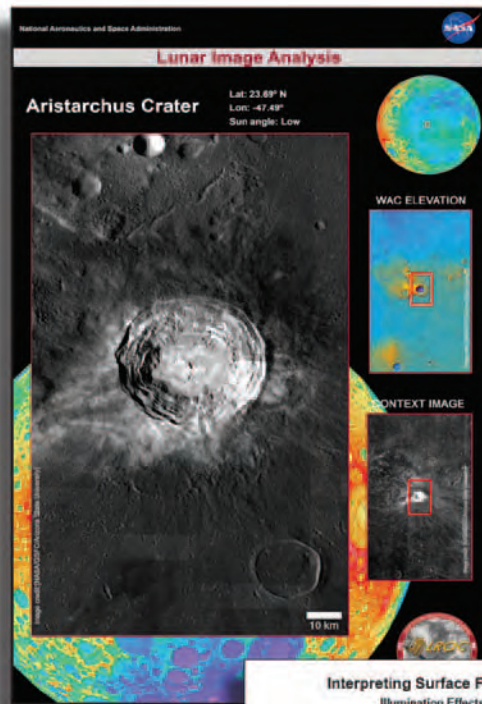


The Topography of the Moon by LROC WAC and LOLA

TASK 2: IDENTIFYING LUNAR FEATURES

For this activity, you will analyze images of the Moon provided by your teacher. As you observe images, be sure to use the **Feature ID Charts** to help you identify and label features with a dry-erase marker. Your teacher will explain the materials and information you have available for this part of the activity and when to fill information into the **Student Data Log**. Here, you will see a sample of the **LROC-WAC Equatorial Mosaic Image**, **Feature ID Charts**, and the **Sunlight and Shadows Sheet** you will be using.

Sample LROC WAC Equatorial Mosaic Image



Sunlight and Shadows Sheet

1: LUNAR FEATURE IDENTIFICATION CHART Primary Craters and Their Features		
Feature	Feature Example	Feature Description
Simple Craters		• Small bowl-shaped craters
Complex Craters		• Large, multi-ringed craters
2: LUNAR FEATURE IDENTIFICATION CHART Secondary Craters and Other Features		
Feature	Feature Example	Feature Description
Crater Chains		• Small secondary impact craters arranged in chains near larger craters
		• Produced by the impact of rocks from a larger impact
		• Often visible as a line of smaller craters
		• Less than 1 km in diameter
		• Small secondary impact craters in clusters formed by the impact of rocks from larger craters
		• These craters can be found in areas around larger craters
		• Molten rocks and regolith that flow from the rim
		• Often found in areas around larger craters
3: LUNAR FEATURE IDENTIFICATION CHART Volcanic Features		
Feature	Feature Example	Feature Description
Maria (Singular: Mare)		• Large flows of basaltic lava that erupted on the surface and flowed into low-lying impact basins
		• Often found in impact basins
		• Often found in impact basins
		• Often found in impact basins
4: LUNAR FEATURE IDENTIFICATION CHART Tectonic Features		
Feature	Feature Example	Feature Description
Fractures		• Cracks in areas where the crust has been pulled apart
		• Can be linear (straight) or curved
		• Usually found in groups
		• Often found in impact basins
		• Often found in impact basins
5: LUNAR FEATURE IDENTIFICATION CHART Mass Wasting Features and Layers		
Feature	Feature Example	Feature Description
Debris Flow		• Loose rocks and debris that has slid down a steep slope
		• Material often piles up at the bottom of a slope
		• Triggered by seismic activity
		• The flow forms ridges that are tongue- or finger-shaped
		• Small-scale features only visible in NAC images
Boulder Trails		• Linear features (trails) formed by boulders that have rolled down slopes
		• Some trails are smooth and others are bumpy
		• Often found in areas near impact craters
		• Small-scale features that are only visible in NAC images
Layers		• Layers are formed by impacts and can be seen in walls of craters
		• They can be seen in the walls of craters
		• Layers build up over time and contain a record of successive lava flows
		• Layer thickness can give important information on the history of lava flows

Lunar Feature Identification Charts (set of five)

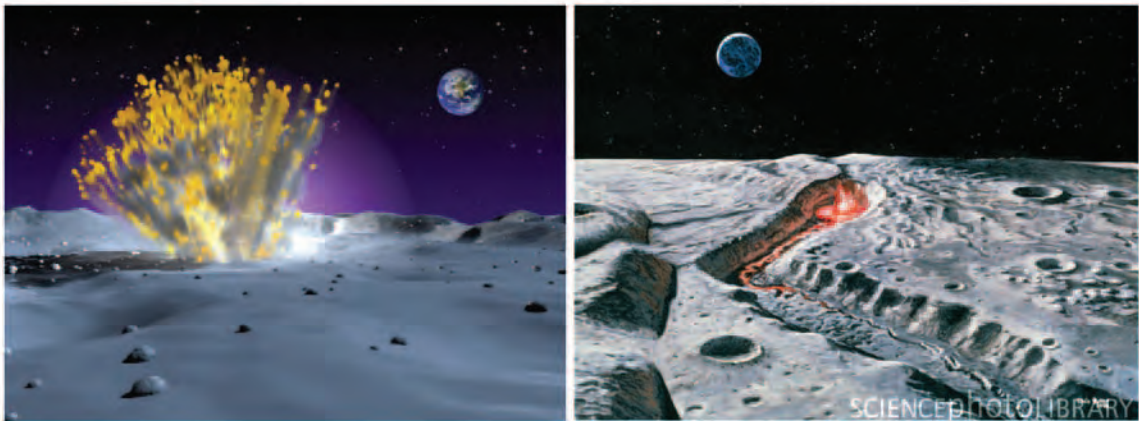
TASK 3: UNRAVELING THE HISTORY

Relative Age: What came first; what came later?

Now that you've identified surface features on your LROC image, take some time to think about the geologic changes that have taken place in this area over time. Scientists use several methods to reconstruct the sequence of geologic events. This is called **Relative Age Dating**.

Relative Age of Features:

While scientists have used instruments to precisely date lunar rock samples (absolute age) collected by Apollo astronauts, these dates are limited to the very small number of specimens collected and only from a few specific areas on the lunar surface (where Apollo astronauts explored). Thus, scientists must rely on other methods to determine geologic age. Another method of dating, called Relative Age Dating, uses several techniques to infer a sequence of geologic events. The downside is exact dates cannot be determined, but it is possible to reconstruct a history by placing geologic events in their order of occurrence. Lunar scientists do this by studying collections of images taken by orbiting spacecraft such as LRO.



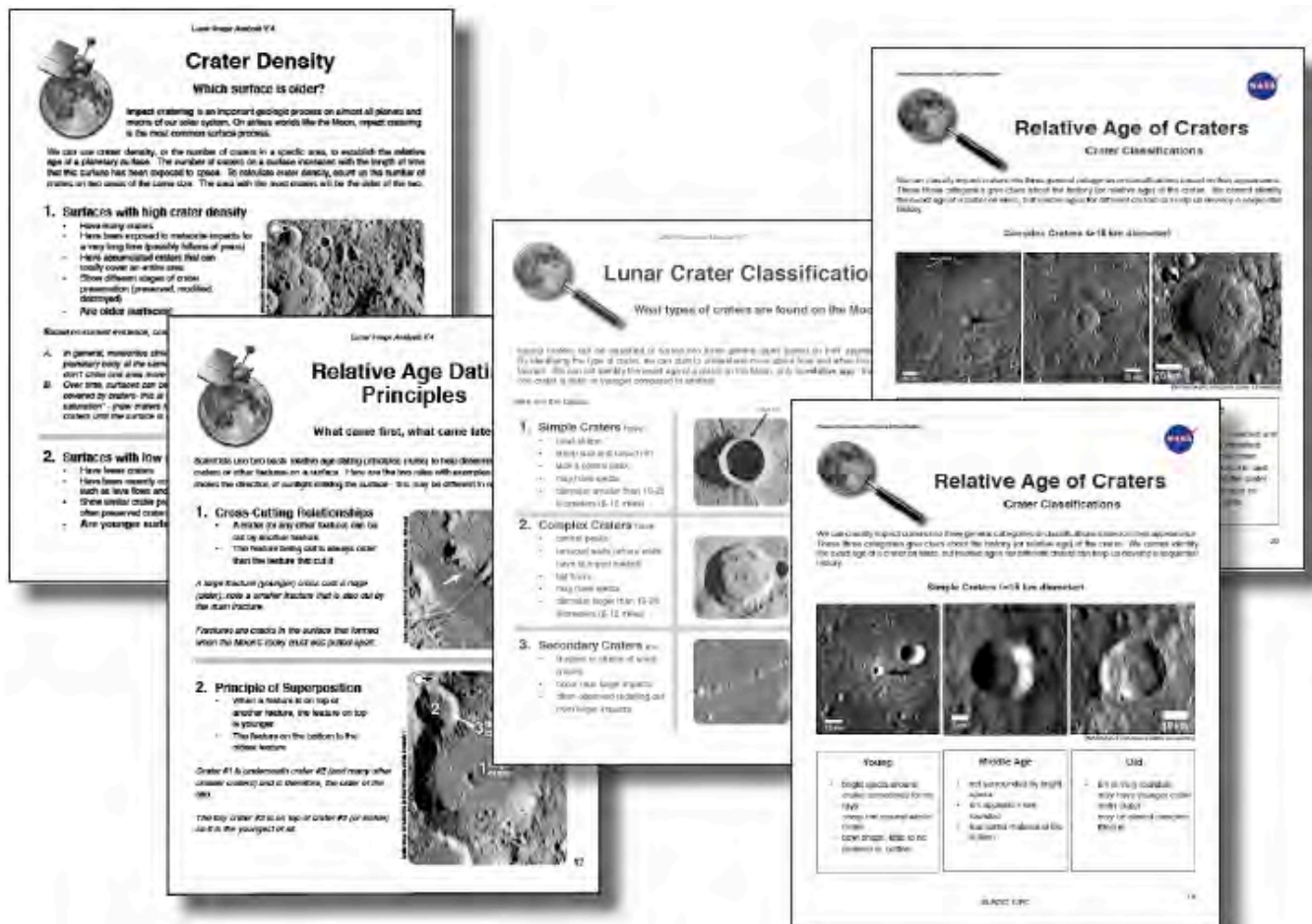
Like Earth, geologic processes such as impacts and volcanic activity have been at work on the Moon for several billion years. What story does your image tell? Use the Age Dating Charts to explore. Credits: NASA and Chris Butler/Science Photo Library.

TASK 3: UNRAVELING THE HISTORY

In this part of the activity, you will further analyze images of the Moon. Now, you will think about the history of the area using relative age dating principle. The most common techniques used for determining the relative age of features on the Moon are:

- **Crater Classifications:** Simple, Complex, and Secondary
- **Relative Age Dating Principles:** Principle of Superposition and Crosscutting
- **Crater Density:** More or less cratering on the Moon

1. Use your dry-erase marker and the Relative Age Dating techniques sheet. Create an order in which these features were formed by marking the oldest feature as a "1," the next oldest as a "2," and so on until all of the features have been appropriately numbered. The youngest feature will have the highest number. If two or more features appear to have the same relative age, mark them with the same number.
2. Once your group has agreed on the order of events, fill in your Student Data Log with this order.



Relative Age Dating Principles Crater Density Charts Lunar Crater Classification (set of three)



Student Data Log

Name _____

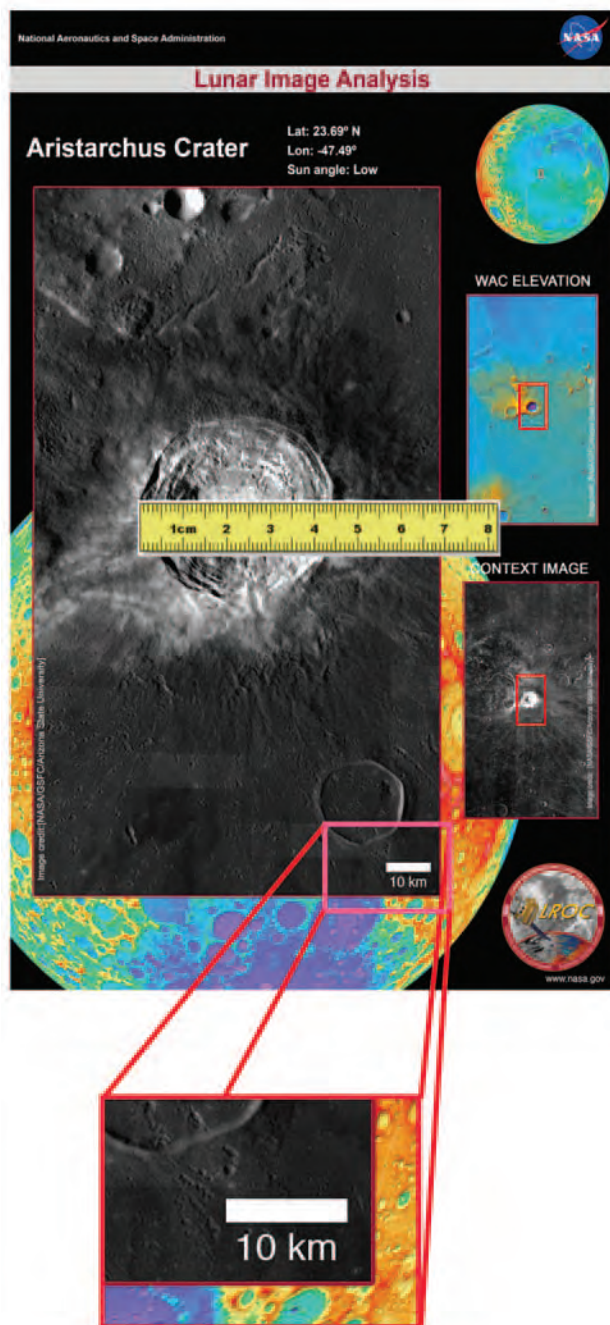
Use this table to order the major (most noticeable) features according to their relative ages chosen. The oldest feature should be numbered 1, next oldest 2, 3, 4, 5, to the youngest number 6.

Feature Name	Age Rank	Describe How Feature Formed
	Oldest	
	Youngest	

Write out a short “history” of the major events that took place in your area. Use the relative age of the features that you listed in your table:

TASK 4: MAKING MEASUREMENTS

For each LROC-WAC Equatorial Mosaic image, you will find a scale bar in the lower right corner. This scale bar can be used to calculate the size of a particular feature on the Moon. Below you will find an example.



Scale Bar

Step 1:

Measure the width of the scale bar in centimeters.

$$2\text{cm}$$

Step 2:

Divide the scale by the width of the scale bar. This will give you a scale factor.

$$10\text{km}/2\text{cm} = 5 \text{ km/cm}$$

This means for every cm you measure, it will represent 5 km on the ground.

Step 3:

Measure the width of the feature in centimeters using a ruler. In this case, we will measure the large crater.

$$8 \text{ cm}$$

Step 4:

Multiply the width of the feature by the scale factor.

$$8\text{cm} \times 5\text{km/cm} = 40\text{km}$$



Student Data Log – Measurements

Use this table to record your feature measurements

Name _____

Step 1: Measure the scale bar _____ cm

Step 2: Divide the scale by the width of the scale bar

_____ km / _____ cm = _____ km/cm

This is your **Scale Factor**. Write this number in the column titled "Scale Factor."

Feature Name	Feature Measurement	×	Scale Factor	=	Feature Actual Size

TASK 5: ESTABLISHING A RESEARCH TOPIC OF INTEREST

Name _____

1. Within your group, brainstorm four **general topics** that can be studied about the Moon. For example: volcanism, cratering, water, human exploration, etc. These can be whatever interests you and your group regarding the Moon.

2. As a class, vote on the topic that is most interesting for your research.

Your class topic for research is: _____

Why Background Research?

Knowing a lot about your topic will help you make better, informed observations. Better observations make for better research questions.

Many of your LROC-WAC Equatorial Mosaic image observations are everyday observations. Everyday observations are very general. These observations are good, but we want to learn more about the Moon. We need to look for features that are important to scientists.

Important observations make great research questions. Great research questions help scientists understand the Moon, where it came from, and its history.

Examples:

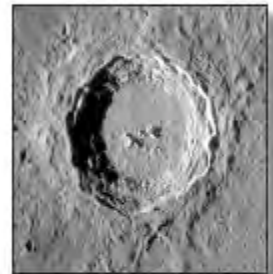
Everyday observation:

- There are many craters in the image.

Scientific observations:

- There are 20 craters in the image that are over 10 km wide.
- 25 craters are destroyed craters.
- There are 34 craters in the rocky areas, but only 2 in the flat areas.
- Not all of the craters with central peaks have rough walls.

Use the next page as a guide for completing your background research. Remember, your goal is to become an expert on your topic.





Background Research

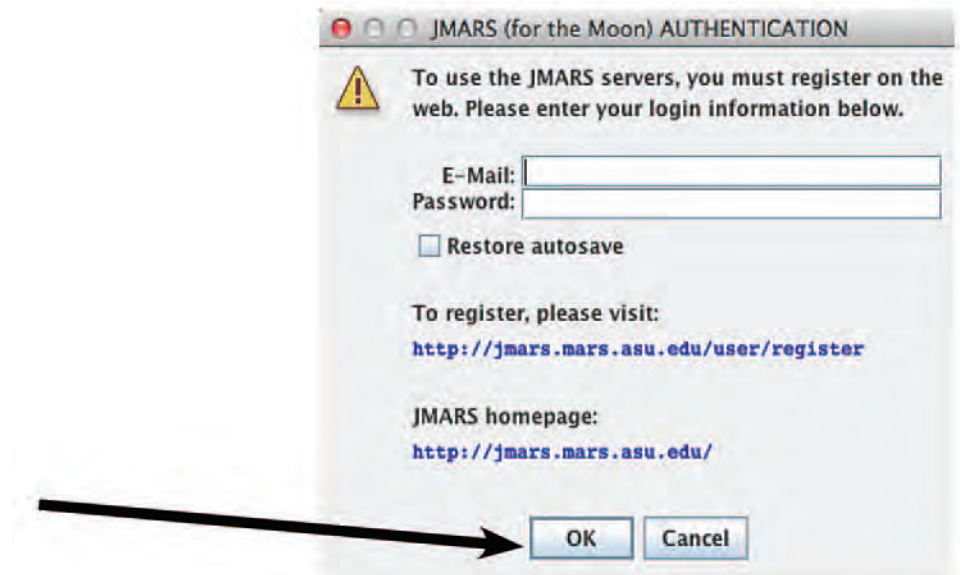
Name _____

Citation (Source):		
How was the feature formed?	Where are they typically found on the Moon?	How are they similar or different from what can be found on Earth or other planetary bodies (planets/ moons?)
Drawing:	Drawing:	Drawing:

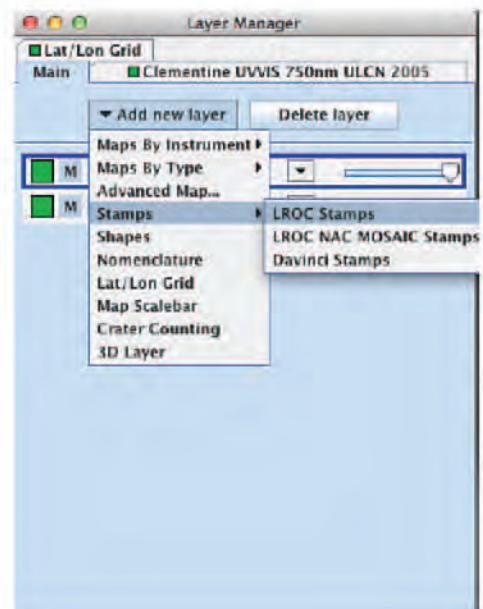
TASK 6: MAKING SCIENTIFIC OBSERVATIONS

This activity will focus on LROC images that show details of many of the geologic features seen on the lunar surface. In this exercise, you will look at LROC-**NAC (Narrow Angle Camera)** and **WAC (Wide Angle Camera)** images and log specific information about each image you observe. Here's what to do:

1. To find images, go to the <http://jmars.asu.edu/> website. Choose the JMARS for Moon Cross-platform WebStart Installer. (You may be asked to register or login with a user name/password. Registration is NOT required to use the tool. Click "OK" to start the application.)



2. Once the JMARS for Moon window opens, you will choose the following:
 - a. Add New Layer > LROC Stamps





3. To pull up LROC image stamps:

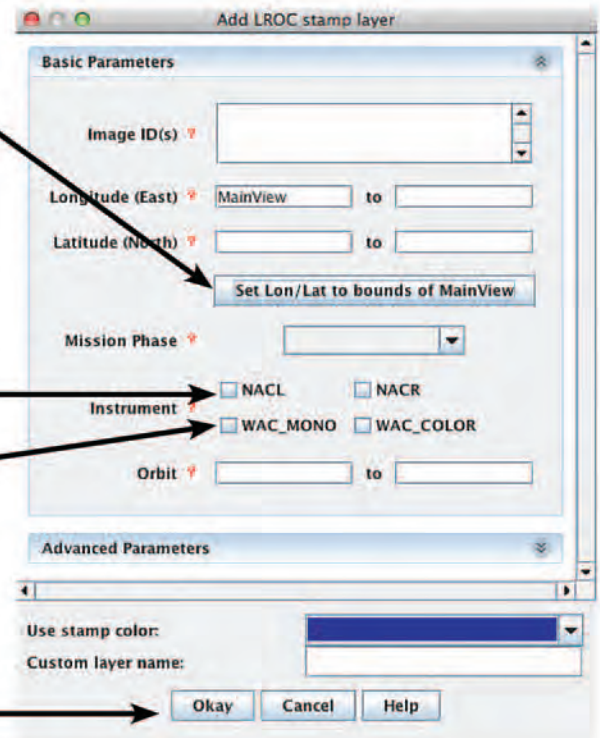
- a. Click Set Lon/Lat to bounds of Main View.

- b. If you want NAC images only, click next to NACL and NACR.

- c. If you want WAC images only, click next to WAC_MONO and WAC_COLOR.

- d. To load all image stamps in the area, leave boxes blank.

- e. Then click Okay at the bottom

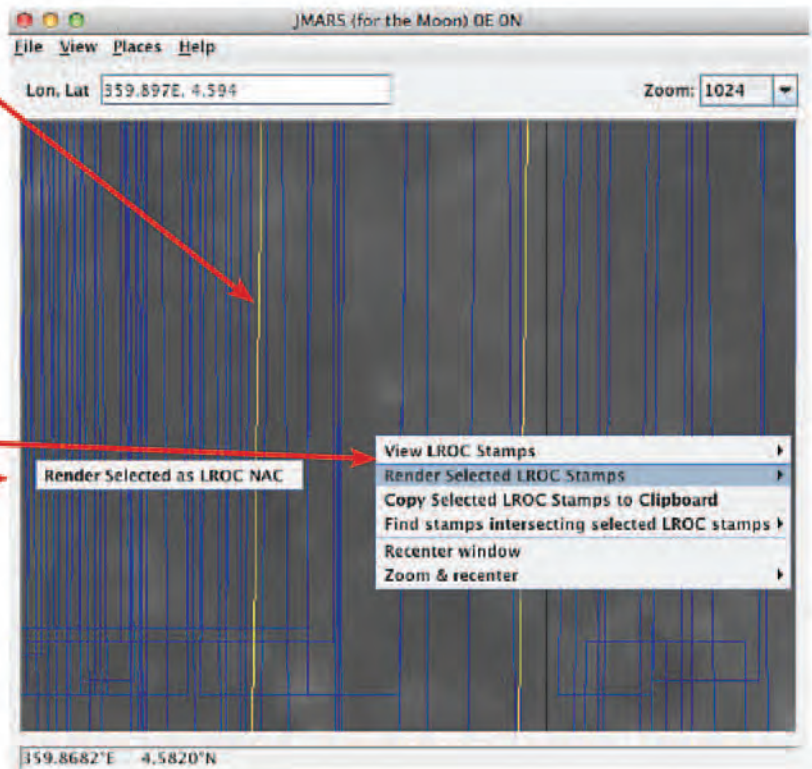


4. To view a specific stamp, select the stamp in the map window

(the outline will turn from blue to yellow).

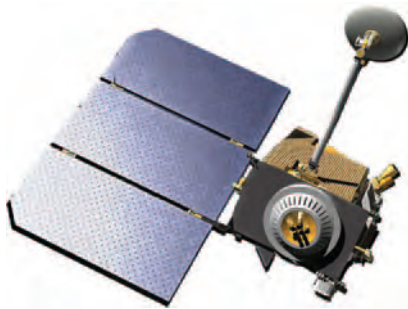
- a. Right click > Render Selected LROC Stamps.

- b. Render Selected as LROC NAC.



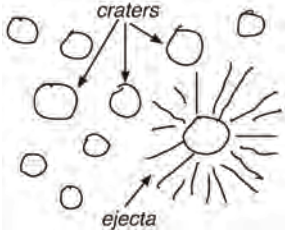


5. Log the following information on your observation worksheets:
- Surface Geologic Feature(s) Observed:** Name the specific surface geologic features you find interesting in each image. Use the Lunar Feature Identification Charts to help identify types of surface features.
 - Image ID Number:** LROC images have an image ID number called a "Product Number." This number is at the top of the LROC Observation page and listed in the Image details section that appears when you click on an image footprint.
 - Sketch the Geologic Feature(s):** Make a sketch or drawing of the portion of the LROC image that shows the feature(s) you are observing. Do not sketch the entire image.
 - Specific Observations of Geologic Feature(s):** Write down specific observations of the feature(s) you sketched. Consider patterns you may look for with these features in other images.



In 2009, NASA returned to the Moon by sending a spacecraft called the Lunar Reconnaissance Orbiter (LRO) to gather crucial data of the lunar environment. LRO was launched in June of 2009 and orbits approximately 50 kilometers (31 miles) above the lunar surface, while its seven instruments find safe landing sites, locate potential resources, characterize the radiation environment and test new technology.

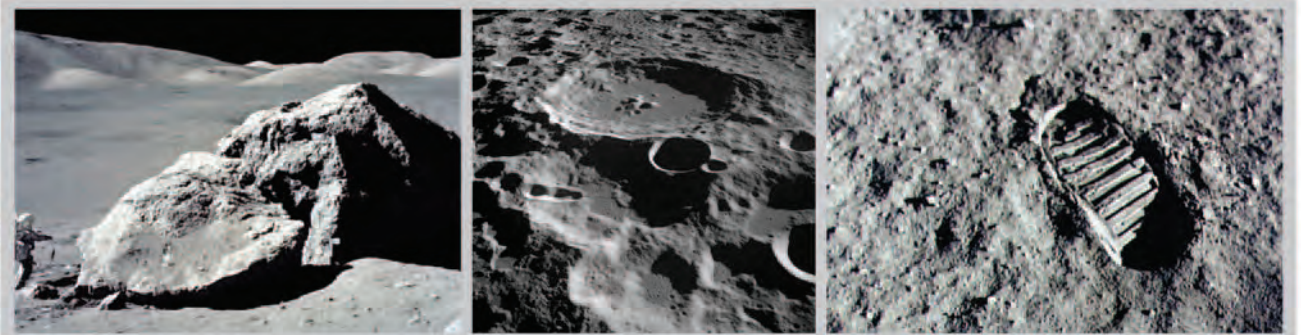
Example Observation Table

Surface Geologic Features Observed & Image ID #	Sketch of Surface Geologic Features	Text Description of Surface Features (use bullets)
Image ID #: M122218152R Area showing many small simple craters some with white and gray ejecta visible.		<ul style="list-style-type: none"> Some craters show bright white ejecta rays that spread out around the rim while other areas show gray rays Craters seem to be about the same size in this area

Make scientific observations:

- Fill out the following set of observation tables.
- Be as detailed as possible as you enter the data in the tables. Remember: your goal is to make scientific observations, not everyday observations. Use your completed Background Research for details on your topic.
- Think about the surface features that you are observing— what interests you?
- Work with students on your team to find other areas on the Moon that have features you all are interested in.

Credit: NASA





Observation Table

Name _____

Making Observations of LROC Images

Surface Geologic Features Observed & Image ID #	Sketch of Surface Geologic Features	Text Description of Surface Features (use bullets)
Image ID #: Features:		
Image ID #: Features:		
Image ID #: Features:		
Image ID #: Features:		



Choosing a Topic for Research

Name _____

1. Review your scientific observations from the Observation Table. Choose two observations you found most interesting during your online research. These are observations you would like to share with the class and could turn into an interesting research project. Record them below:

Observation #1	Observation #2

2. After a class discussion about interesting scientific observations, list **six major relevant categories (or features) within your topic** the class can choose to study about the Moon. For example, with volcanism, think about related surface features such as lava flows, eruptions, volcanoes, or ash and rock deposits. Once you have created the list, as a team debate and select a specific topic and relevant category.

3. List the **topic** your group will research: _____

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Figure 1: Pathways

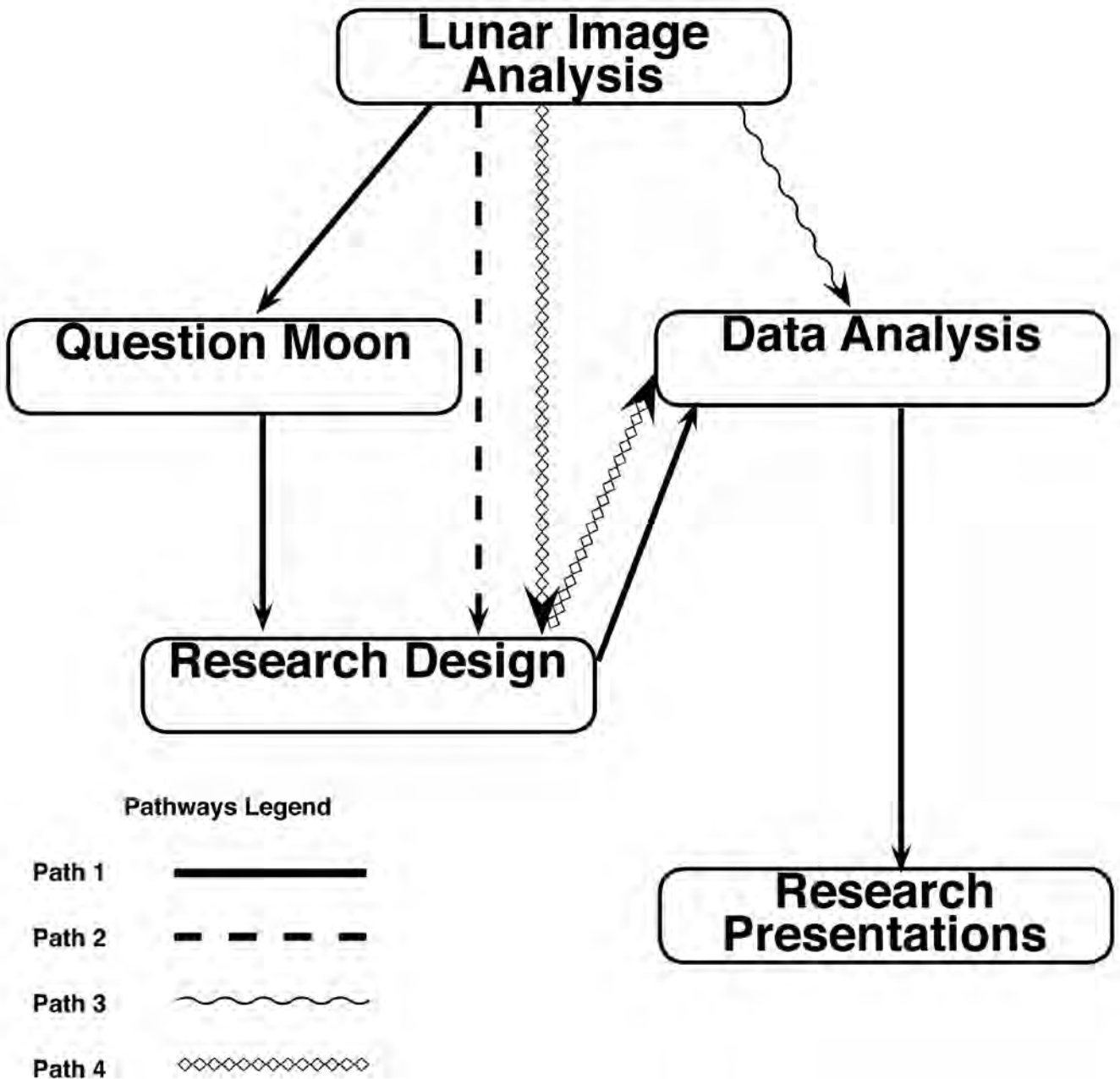


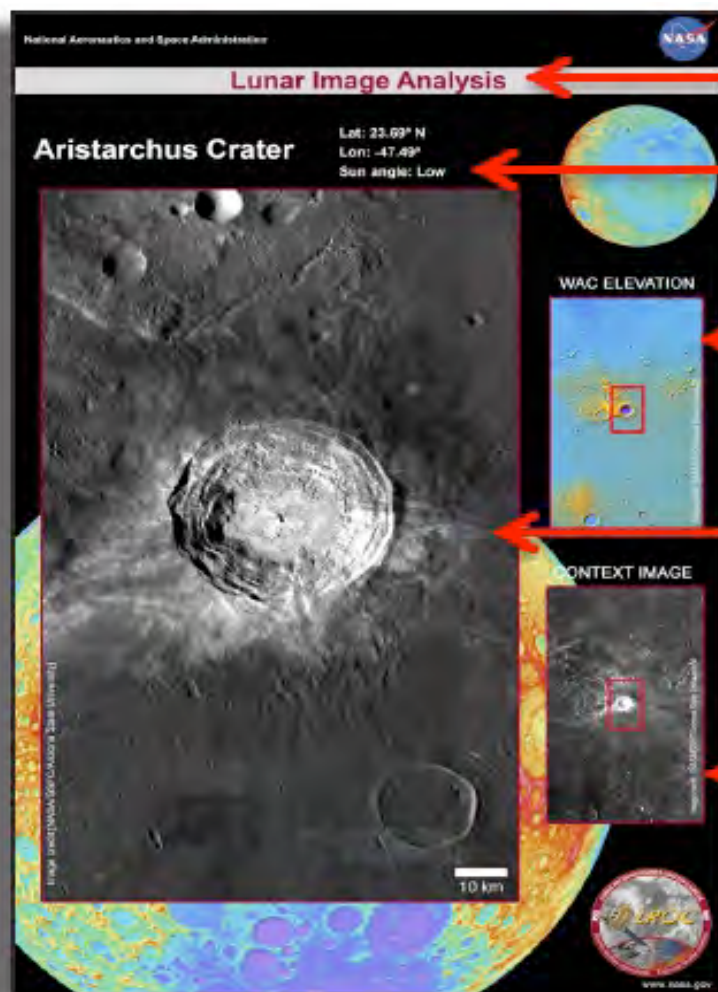
Figure 2: Pathways

Emphasis	Lessons in the Path	National Standards	Est. # of Class periods (45 min segments)
Path 1 Full scientific process of research	Lunar Image Analysis Question Moon Moon Research Design Moon Data Analysis Moon Research Publication	Science Dimension 1: Practices 1, 2, 3, 4, 5, 6, 7, 8 Dimension 2: Concept 1, 2, 3, 4 Dimension 3: ESS ESS1C Some types of research: ESS2A, ESS2B, ESS2C, ESS2D	25
Path 2 Developing observation skills and controlled experimental procedures	Lunar Image Analysis Moon Research Design	Science Dimension 1: Practices 2,3 Dimension 2: Concept 2, 3, 4 Dimension 3: ESS ESS1C	5
Path 3 Developing observation skills, graphing techniques, and graphical interpretation	Lunar Image Analysis Moon Data Analysis	Science Dimension 1: Practices 4, 5, 6 Dimension 2: Concept 1, 2, 3, 4 Dimension 3: ESS ESS1C	5
Path 4 Developing observation skills, controlled experimental procedures, graphing techniques, and graphical interpretation	Lunar Image Analysis Moon Research Design Moon Data Analysis	Science Dimension 1: Practices 2, 3, 4, 5, 6, 7 Dimension 2: Concept 1, 2, 3, 4 Dimension 3: ESS ESS1C	8

Scientific Observations and Debate Skills Rubric

	Expert	Proficient	Intermediate	Beginner
Scientific Observations	<ul style="list-style-type: none"> Differentiates between common features and unique features on the Moon and begins hypothesizing about why these features appear or establishing patterns. Illustrations of these features demonstrates the connection to a possible pattern. Explains the differences between the common and unique features of the Moon using specific criteria and subject specific knowledge 	<ul style="list-style-type: none"> Differentiates between common features associated with a surface feature on the Moon, and those that appear unique. Illustrates these unique and common features of the Moon. Explains the differences between the common and unique features of the Moon. 	<ul style="list-style-type: none"> Identifies features on the Moon that are both common and unique. Illustrates each feature. Explains each feature using correct terminology in feature identification and specific details in the descriptions 	<ul style="list-style-type: none"> Identifies features on the Moon. Illustrates each feature. Uses correct terminology in feature identification. Uses specific details in descriptions.
Debate Skills	<ul style="list-style-type: none"> Identifies and critiques arguments in which the claims are not consistent with the evidence given using the claims, evidence, and reasoning model. Exemplifies scientific discussions to allow for differing opinions, observations, experiences, and perspectives. Uses self-created hypotheses to explain the meaning in observations. 	<ul style="list-style-type: none"> Uses claims, evidence, and reasoning. Exemplifies scientific discussions to allow for differing opinions, observations, experiences, and perspectives. Infers the meaning of the observations (starts hypothesizing). 	<ul style="list-style-type: none"> Explains reasoning behind agreement and/or disagreement with participants. Uses claim and reasoning portion of the model. 	<ul style="list-style-type: none"> Generates a claim. Participates in discussion. Uses previous knowledge to support a claim in discussion. Agrees and/or disagrees with participants.

Teacher Resource #1



Title: Names the general region where the image is located on the Moon.

Latitude and Longitude: Exact location of this image on a map of the Moon.

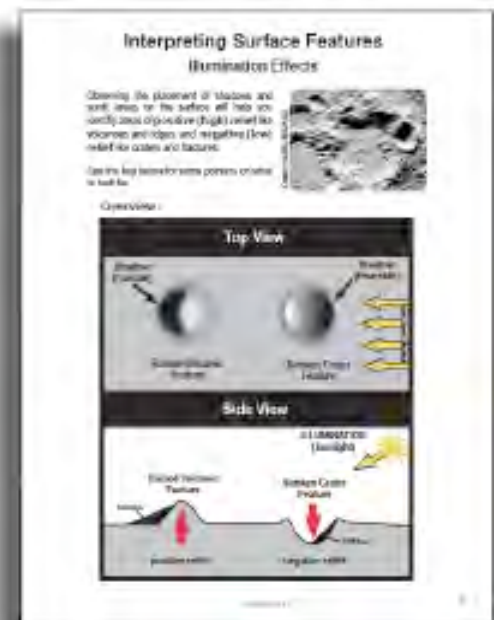
LROC-WAC with LOLA elevation: Colorized elevation of the surface of the Moon.

LROC-WAC Equatorial Mosaic: The long, rectangular image of the Moon. Mosaic of LROC WAC images.

Context Image: Shows the area surrounding the LROC-WAC Equatorial Mosaic.

SUNLIGHT AND SHADOWS

The Sunlight and Shadows sheet will help students to identify features in their LROC-WAC Mosaic by orienting them to how shadowing is used to identify a raised or carved feature. Some students may need additional practice with this concept, using concrete materials such as a cup and flashlight. Have students discover how the lighting works with the cup turned right-side up and up-side down.



Context Image: Shows the area surrounding the LROC-WAC Equatorial Mosaic.

Teacher Resource #2

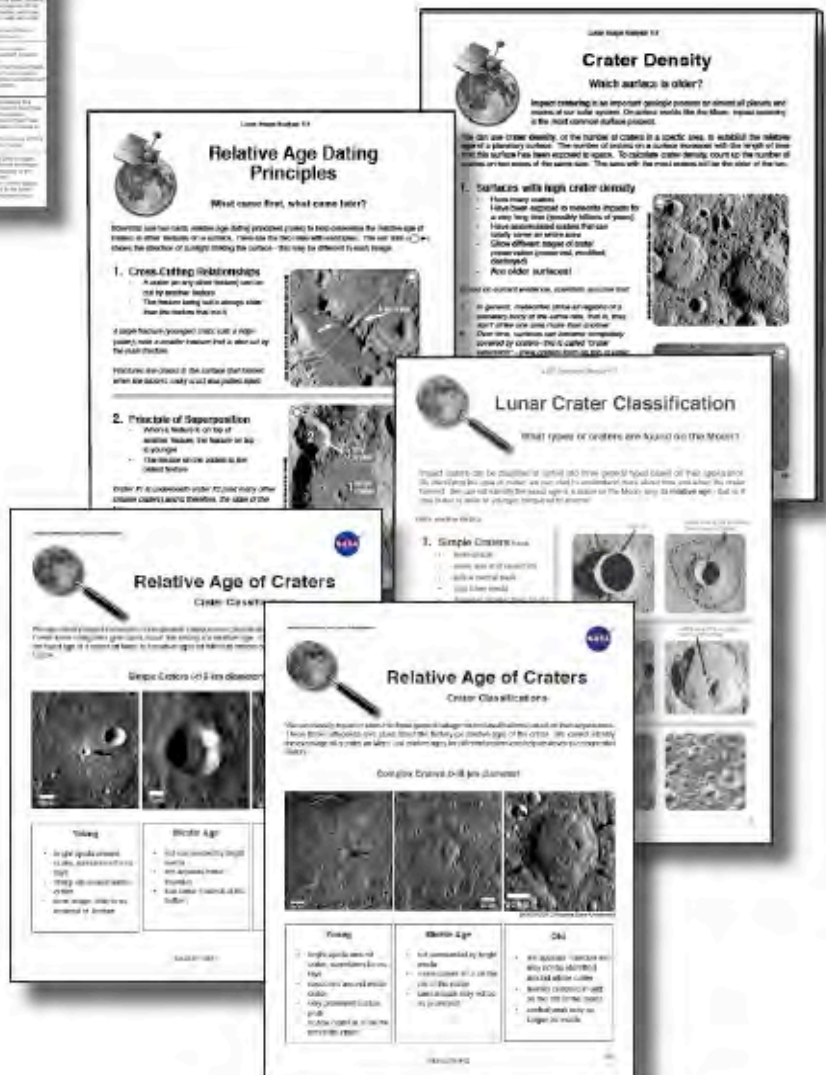


◀ FEATURE IDENTIFICATION CHARTS

The Feature ID Charts will help students learn the names of different geologic features on the Moon. They also provide information on how features form. The information at the top of each chart indicates what geologic process the listed features are associated with. There are many other features students may observe in images that are not included on these charts. Encourage students to share other features they may know.

RELATIVE AGE HANDOUTS ➤

Students will be able to use the Crater Density, Lunar Crater Classification, Relative Age of Craters, and Relative Age Dating Principles sheets to identify what features are older or younger. This will help them better understand the geologic history of the surface.



Sunlight and Shadows

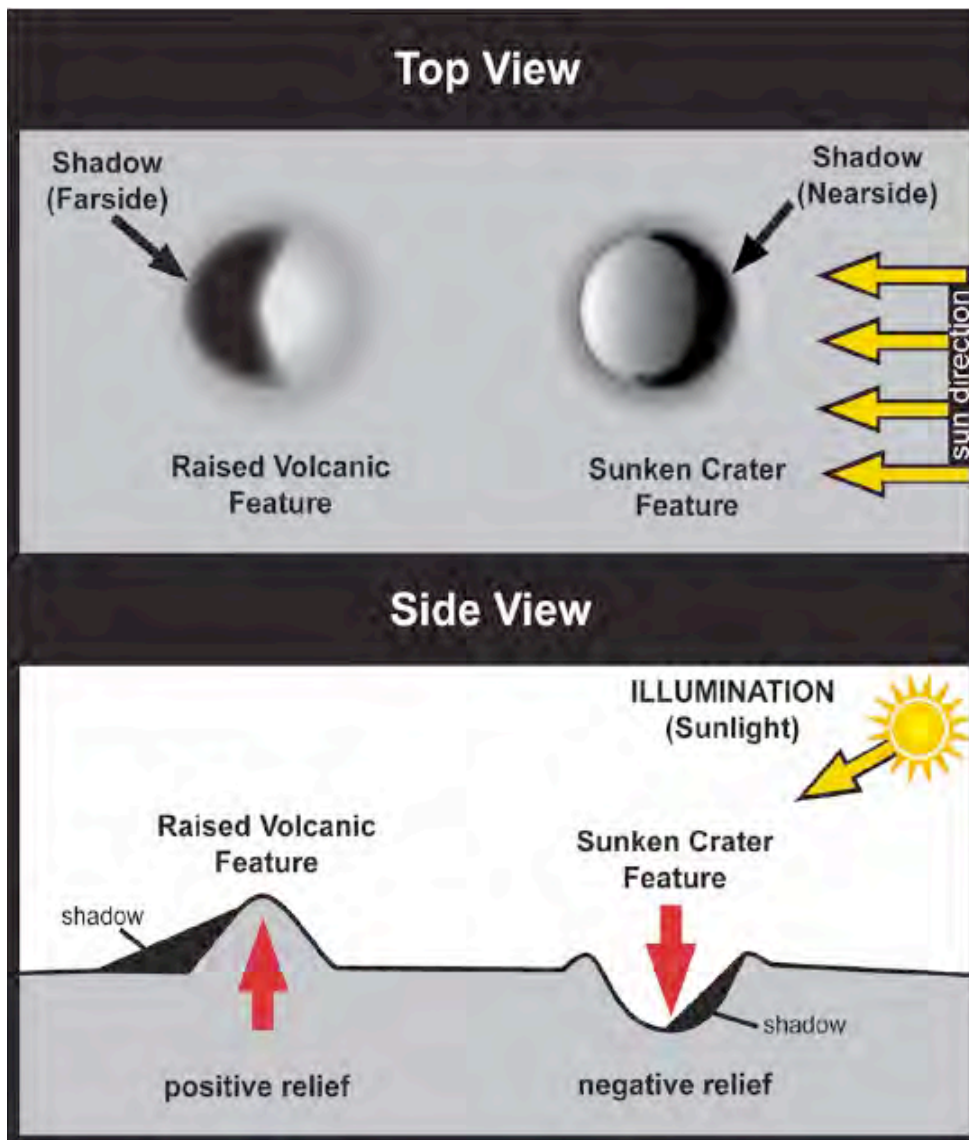
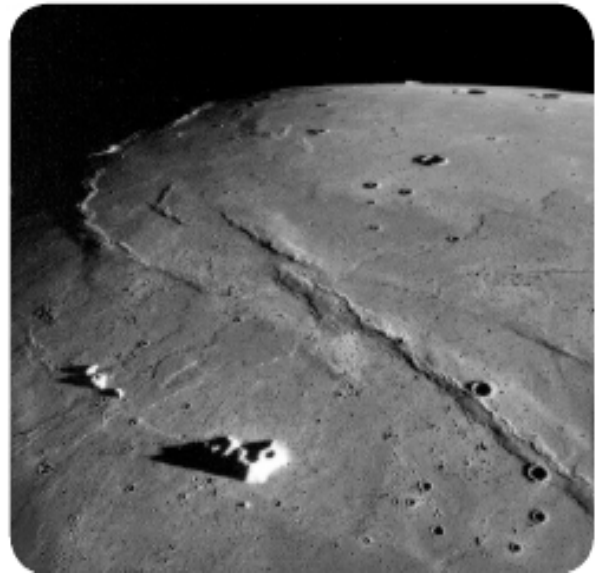
Observing the position of shadows and sunlit areas on the Moon's surface will help you identify areas of **positive (high) relief** like volcanoes and ridges, and **negative (low) relief** like craters and fractures.

See the key below for some pointers on what to look for as you start working with lunar images.

When the Sun is low in the horizon, light strikes the surface at low angles making long shadows. This geometry enhances surface features (image at right). See the key below for some pointers on what to look for as you start working with lunar images.

When the Sun is low in the horizon, light strikes the surface at low angles making long shadows. This geometry enhances surface features (image at right).

Apollo image AS15-M-1555 [NASA/JSC/ASU]



Lunar Crater Classification

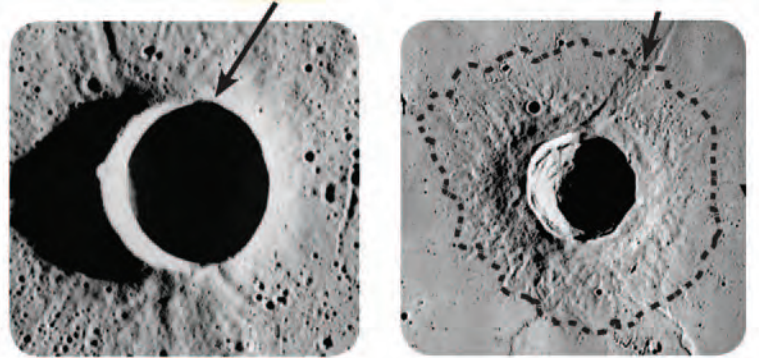
WHAT TYPES OF CRATERS ARE FOUND ON THE MOON?

Impact craters can be classified or sorted into three general types, based on their appearance. By identifying the type of crater, we can start to understand more about how and when the crater formed.

Here are the basics:

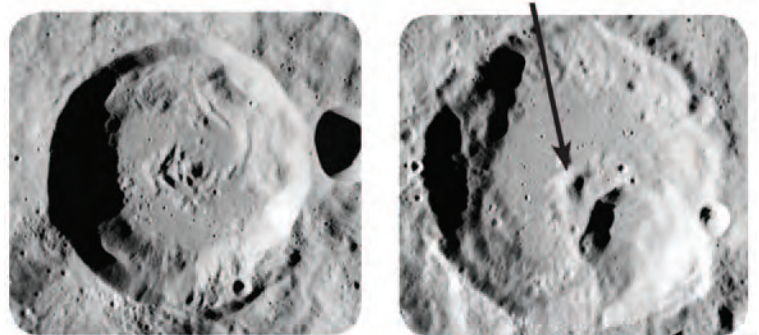
1. Simple Craters have:

- bowl-shape
- steep wall and raised rim
- lack a central peak
- may have ejecta
- diameter smaller than 10-20 kilometers (6-12 miles)



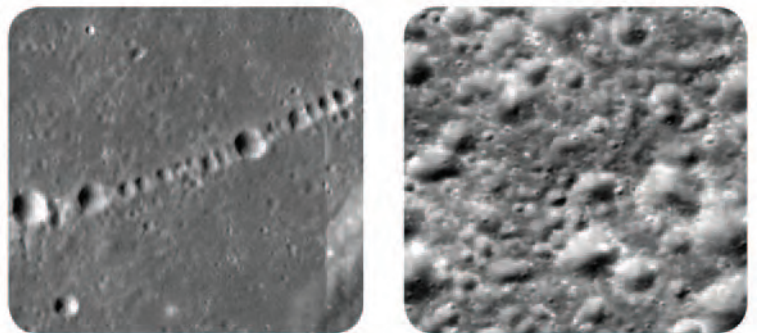
2. Complex Craters have

- central peaks
- terraced walls (where walls have slumped inward)
- flat floors
- may have ejecta
- diameter larger than 10-20 kilometers (6-12 miles)



3. Secondary Craters are:

- clusters or chains of small craters
- occur near large impacts
- often observed radiating out from larger impacts

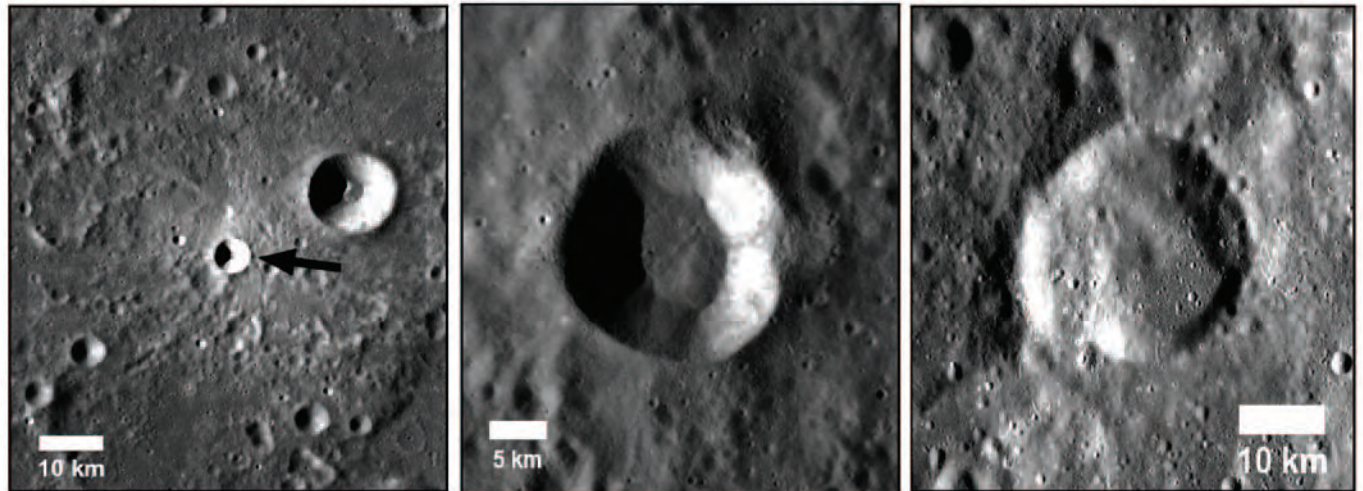


Relative Age of Craters

CRATER CLASSIFICATIONS

These three categories give clues about the history (or relative age) of the crater. We cannot identify the exact age of a crater on the Moon, but relative ages for different craters can help us develop a sequential history.

Simple Craters (<15 km diameter)



NASA/GSFC/Arizona State University

Young

- Bright ejecta around crater, sometimes forms rays
- Sharp rim around whole crater
- Bowl shape, little to no material at bottom

Middle Age

- Not surrounded by bright ejecta
- Rim appears more rounded as some material at the bottom

Old

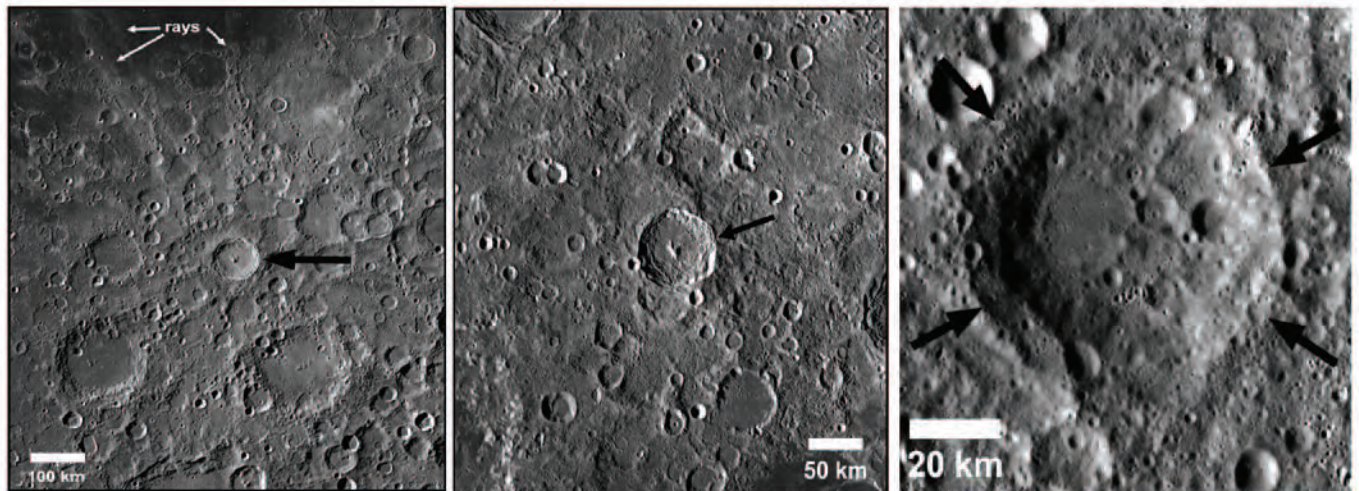
- Rim is very rounded
- May have younger crater on/in crater
- May be almost complete filled in

Relative Age of Craters

CRATER CLASSIFICATIONS

We can classify impact craters into three general categories or classifications based on their appearance. These three categories give clues about the history (or relative age) of the crater. We cannot identify the exact age of a crater on Mars, but relative ages for different craters can help us develop a sequential history.

Complex Craters (>15 km diameter)



NASA/GSFC/Arizona State University

Young

- Bright ejecta around crater, sometimes forms rays
- Raised rim around whole crater
- Very prominent central peak
- No/few crater in or on the rim of the crater

Middle Age

- Not surrounded by bright ejecta
- More craters in or on the rim of the crater
- Central peak may not be as prominent

Old

- Rim is very rounded and may not be identified around whole crater
- Heavily cratered in and on the rim of the crater
- Central peak may no longer be visible

Crater Density

WHICH SURFACE IS OLDER?

Impact cratering is an important geologic process on almost all planets and moons of our solar system. On the Moon, impact cratering is the most common surface process. We can use crater density, or the number of craters in a specific area, to establish the relative age of a planetary surface. The number of craters on a surface increases with the length of time the surface was exposed to space. To calculate crater density, count up the number of craters on two areas of the same size. The area with the most craters will likely, though not always, be the older of the two.

1. Surfaces with high crater density

- Have many craters
- Have been exposed to meteorite impacts for a very long time (possibly billions of years)
- Have accumulated craters that can totally cover an entire area
- Show different stages of crater preservation (preserved, modified, destroyed)
- **Are older surfaces!**

Based on current evidence, scientists assume that:

- In general, meteorites strike all regions of a planetary body at the same rate; that is, they don't strike one area more than another
- Over time, surfaces can become completely covered by craters— this is called “crater saturation” (new craters form on top of older craters until the surface is completely covered)

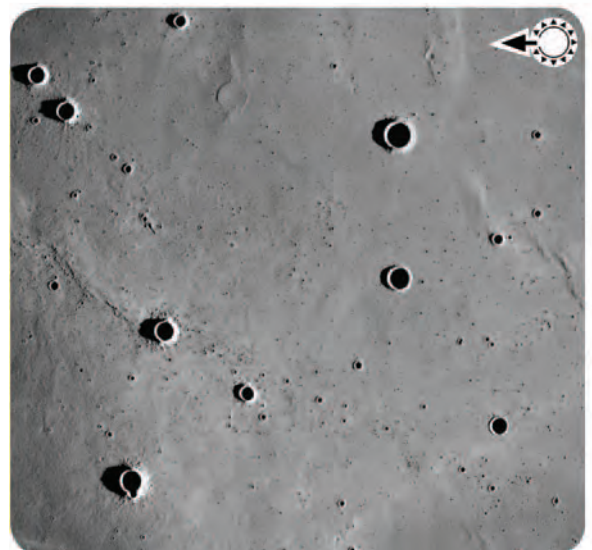
Apollo Image AS15-M-2211 [NASA/JSC/Arizona State University]



2. Surfaces with low crater density

- Have fewer craters
- Have been recently covered by materials such as lava flows and sediments
- Show similar crater preservation, often preserved craters
- Are younger surfaces!

Apollo Image AS15-M-2480 [NASA/JSC/Arizona State University]



Direction of sunlight striking the surface.

Relative Age Dating Principles

WHICH FEATURES CAME FIRST? WHICH CAME LATER?

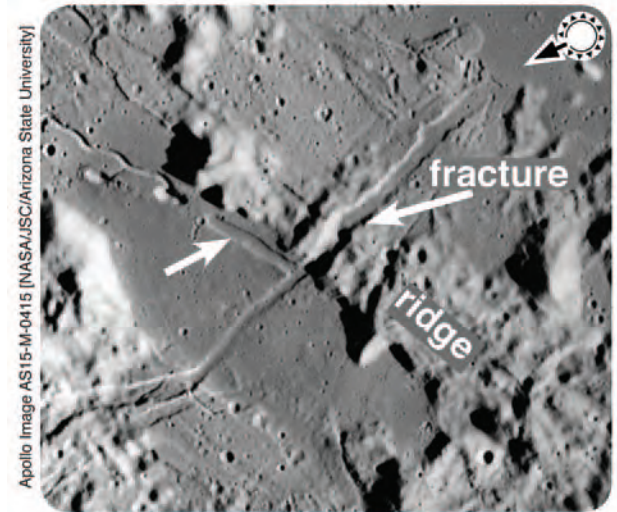
Scientists use two basic relative age dating principles to help determine the relative age of craters or other features on a surface. Here are the two principles with examples. The Sun icon shows the direction of sunlight striking the surface and may be different in each image.

1. Cross-Cutting Relationships

- A crater (or any other feature) can be cut by another feature
- The feature being cut is always older than the feature that cut it

A large fracture (younger) cross cuts a ridge (older); note a smaller fracture that is also cut by the main fracture.

Fractures are cracks in the surface that formed when the Moon's rocky crust was pulled apart.

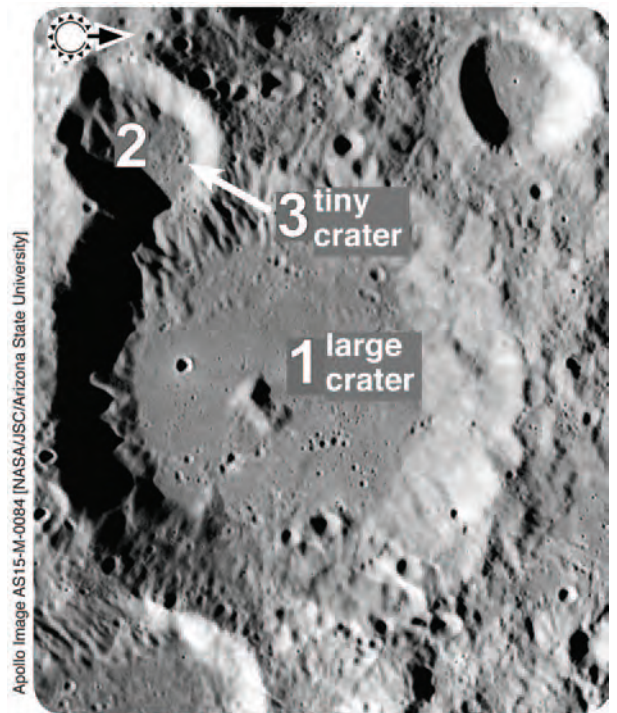


2. Principle of Superposition

- When a feature is on top of another feature, the feature on top is usually younger
- The feature on the bottom is usually the oldest feature

Crater #1 is underneath Crater #2 (and many other smaller craters) and is therefore the older of the two.

The tiny crater #3 is on top of crater #2 (or inside) so it is the youngest of all.



Supplemental #1

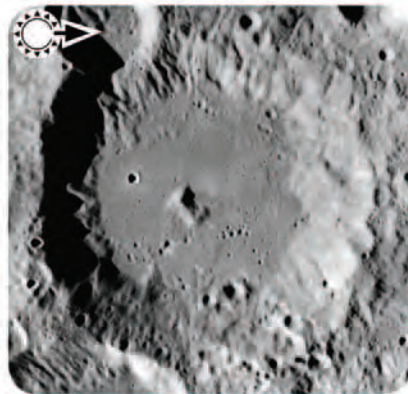
CLASSIFYING CRATERS

Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

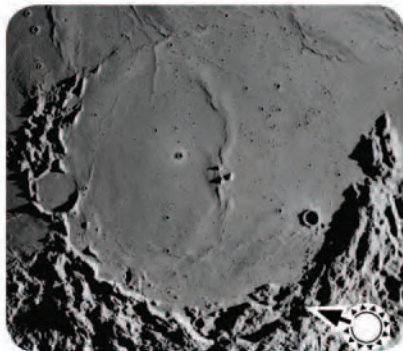
Crater Image	Crater Classification (Simple, Complex, Secondary & Preserved, Modified, Degraded)	Explain Your Reason
Crater A		
Crater B		
Crater C		
Crater D		



Crater A



Crater B



Crater C

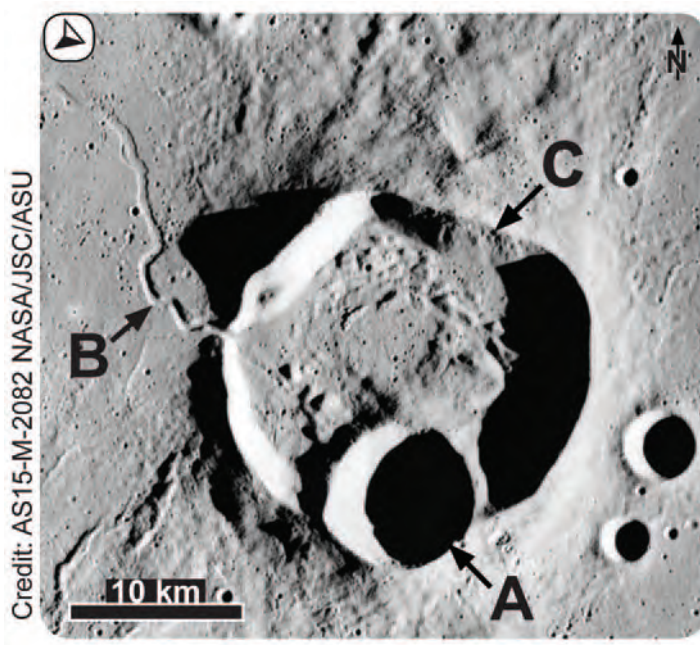


Crater D

Supplemental #2

RELATIVE AGE DATING PRINCIPLES

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



1. Krieger Crater, Moon

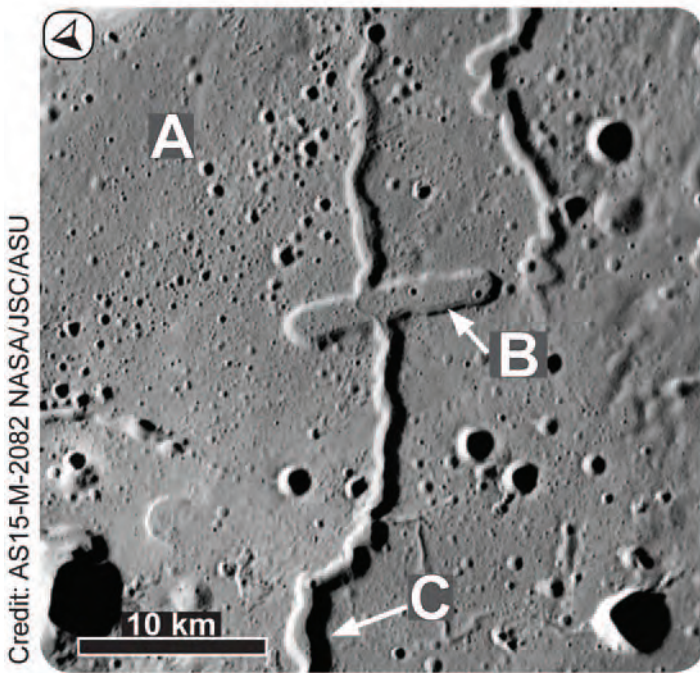
Oldest Crater: _____

Younger Crater: _____

Youngest Crater: _____

Please explain your answers: _____

Which principle(s) did you use to choose your answer?



2. Aristarchus-Prinz region, Moon

Oldest Feature: _____

Younger Feature: _____

Youngest Feature: _____

Please explain your answers: _____

Which principle(s) did you use to choose your answer?

Supplemental #1: SAMPLE ANSWERS

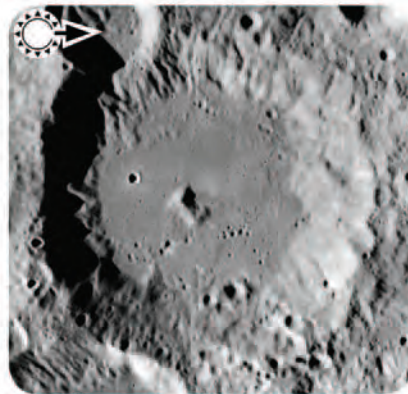
CLASSIFYING CRATERS

Based on the *Crater Classification* information sheet, classify the craters below. Be sure to explain your reasoning for each classification.

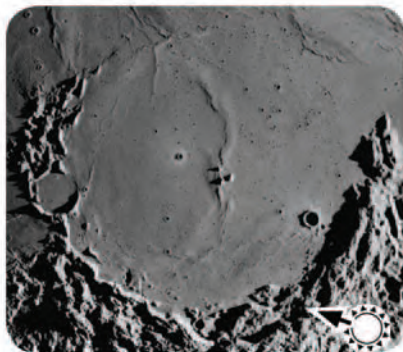
Crater Image	Crater Classification (Simple, Complex, Secondary & Preserved, Modified, Degraded)	Explain Your Reason
Crater A	Simple & Preserved	Raised, circular rims with bowl shape; ejecta visible; crater looks new
Crater B	Complex & Degraded	Rim no longer raised and crater floor flat; remnant of a central peak
Crater C	Simple & Secondary	Small cluster of craters, arranged in a line, simple structure
Crater D	Simple & Preserved	Raised, circular rims with bowl shape; some ejecta visible; crater looks new



Crater A



Crater B



Crater C

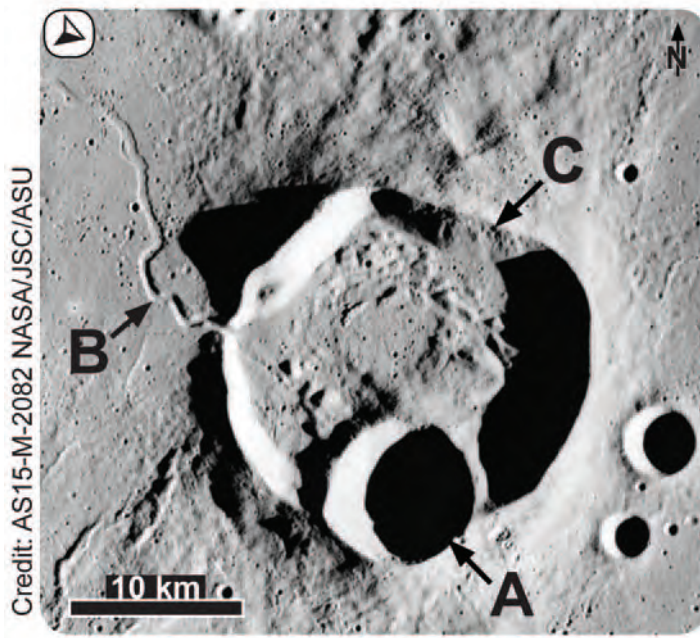


Crater D

Supplemental #2: SAMPLE ANSWERS

RELATIVE AGE DATING PRINCIPLES

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images.



1. Krieger Crater, Moon

Oldest Crater: C

Younger Crater: B

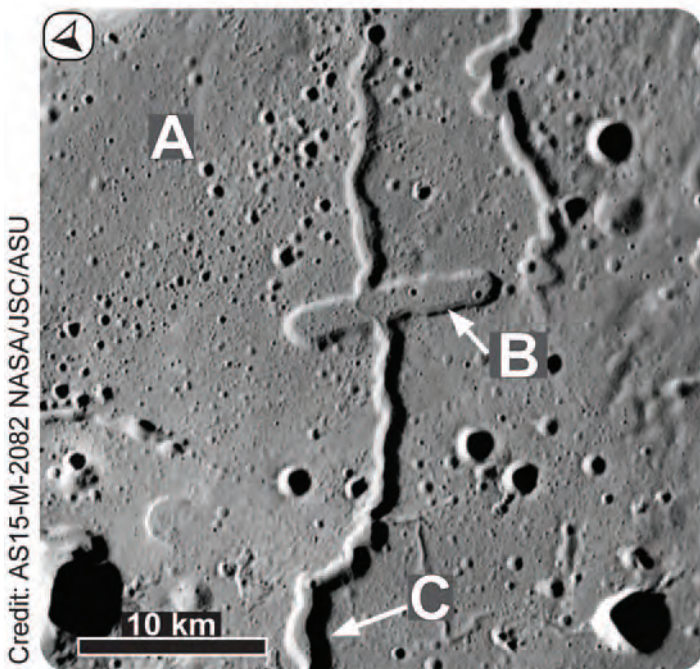
Youngest Crater: A

Please explain your answers:

The channel (B) is younger than crater C since it cuts it. Crater A is the youngest since it sits on top of crater C and the channel.

Which principle(s) did you use to choose your answer?

Principle of Superposition



2. Aristarchus-Prinz region, Moon

Oldest Feature: A

Younger Feature: C

Youngest Feature: B

Please explain your answers:

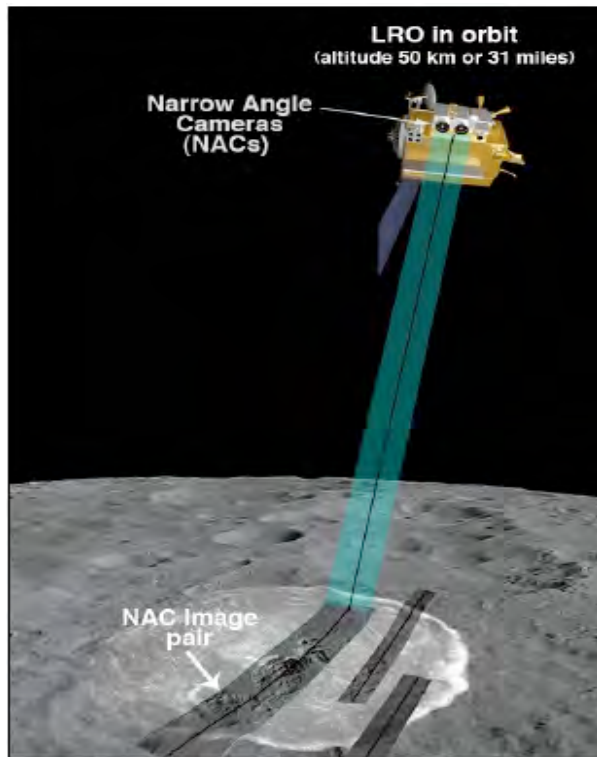
A is the oldest feature (original surface); the channel C is younger since it cuts across the surface; and, the valley B cuts C and is youngest.

Which principle(s) did you use to choose your answer?

Cross-cutting Relationships

What is LROC?

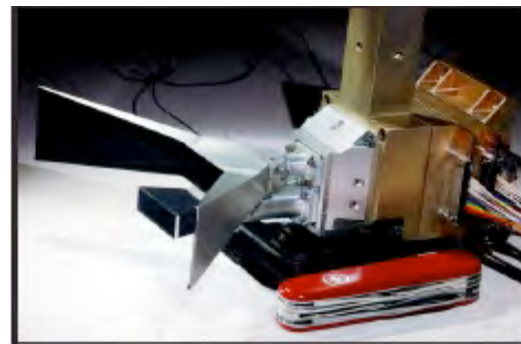
The **Lunar Reconnaissance Orbiter Camera (LROC)** is the camera system on the Lunar Reconnaissance Orbiter (LRO), which orbits the Moon. LROC has two **Narrow Angle Cameras (NACs)**, taking 0.5 meter-scale black and white images over a 5 kilometer area (~3 miles), one **Wide Angle Camera (WAC)**, taking images at a scale of 100 meters (about the length of a football field), and a common **Sequence and Compressor System (SCS)** to organize image data before transmitting it to Earth.



Narrow Angle Camera (NAC)

NAC Stats:

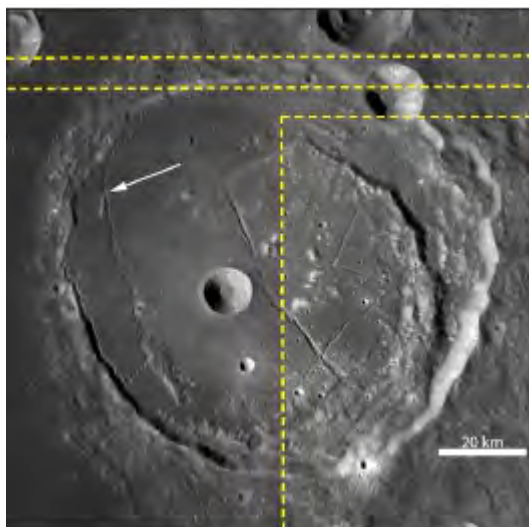
- Black & white image pairs (right and left images)
- 0.5 meters/pixel resolution
- 2.5x26 kilometers image size
- Good for viewing small features



Wide Angle Camera (WAC)

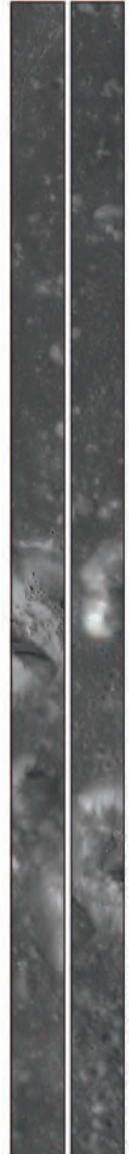
WAC Stats:

- Images in 7 color bands
- 74.3 meters/ pixel resolution for visible (black and white)
- Good for viewing large features and context areas



WAC Mosaic

Composed of many WAC images (yellow dotted lines mark the boundary of individual images)



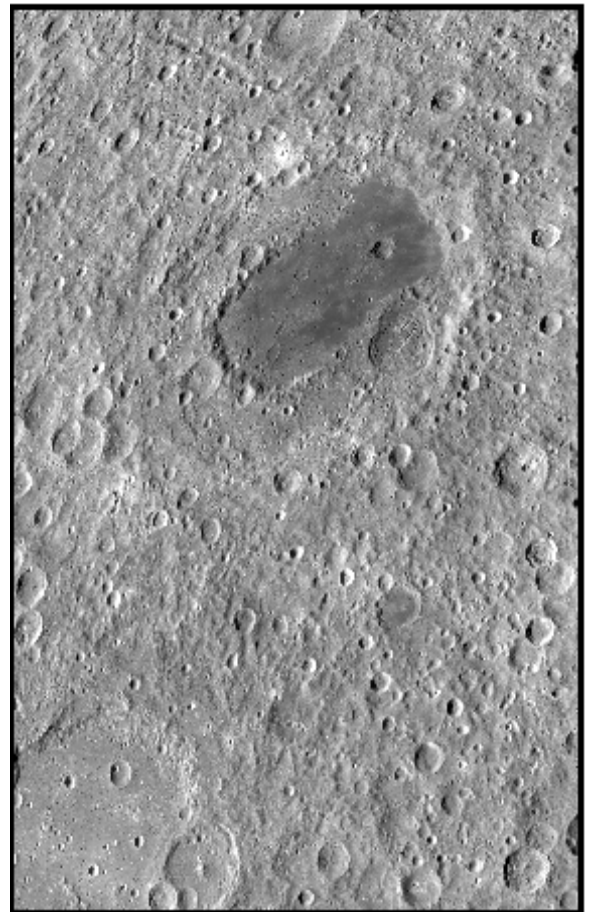
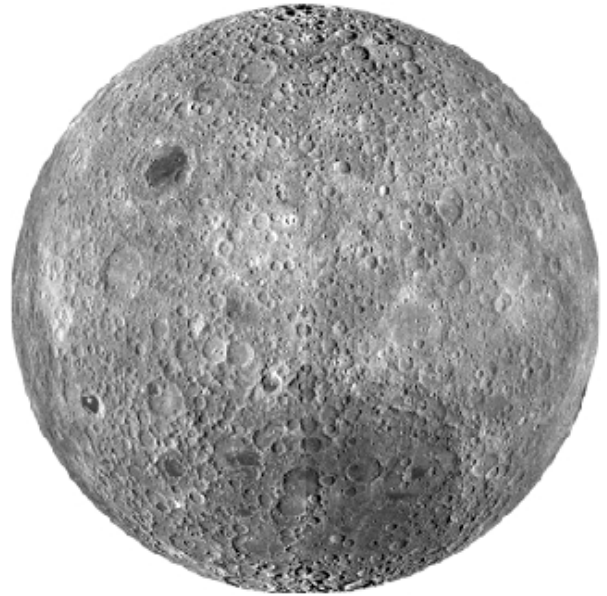
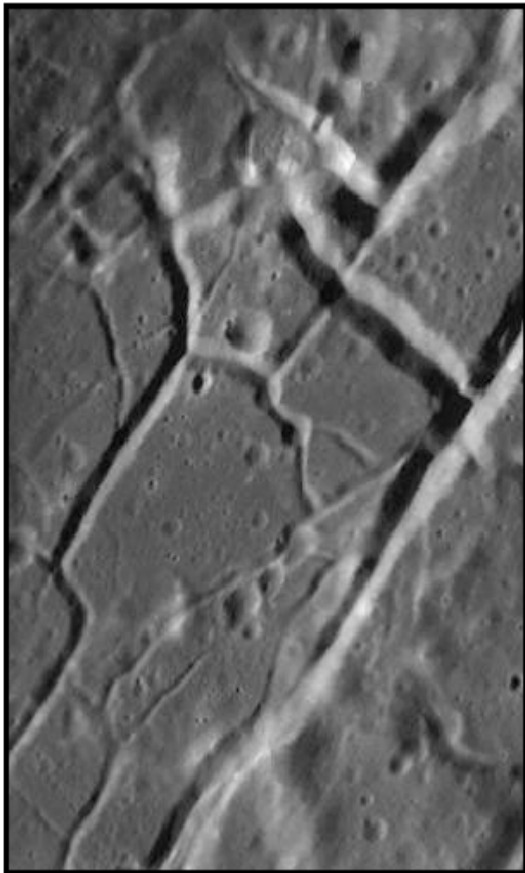
left right

**NAC
Image
Pair**

Credit: NASA/GSFC/Arizona State University

How are these images related?

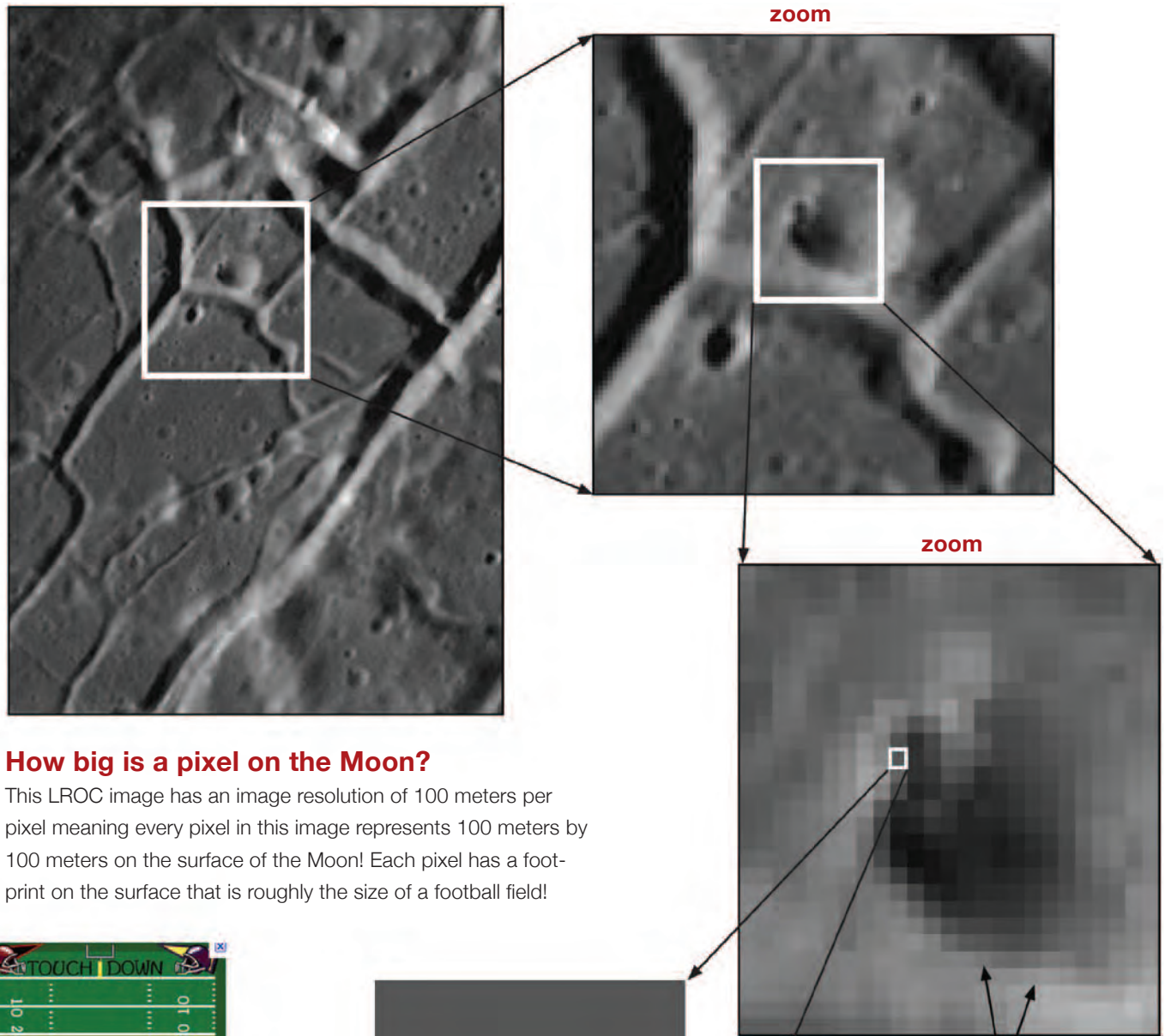
Here are four LROC images of the Moon's surface. How are they related? Look carefully at them and see if you can figure out how they are connected. Draw arrows or labels to help explain your answer.



What is image resolution?

LROC Wide Angle Camera (WAC) Image

Image Resolution = 100 meters per pixel



How big is a pixel on the Moon?

This LROC image has an image resolution of 100 meters per pixel meaning every pixel in this image represents 100 meters by 100 meters on the surface of the Moon! Each pixel has a foot-print on the surface that is roughly the size of a football field!



football field



Statue of
Liberty

100 meters

one pixel

100 meters

pixels

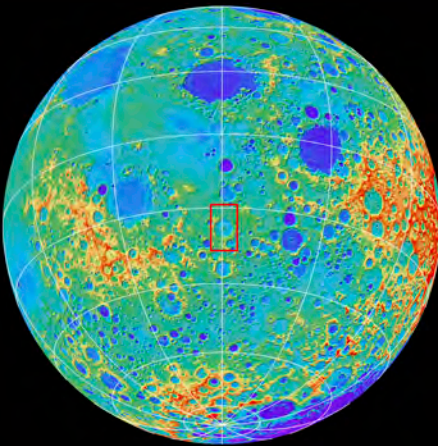
A **pixel** - short for "picture element" - is the smallest unit of an image. It's shown as a square or dot of a single color or shade.



Lunar Image Analysis

Rimae Petavius

Lat: -25.25° N
Lon: 60.70° E
Sun angle: Low



WAC ELEVATION

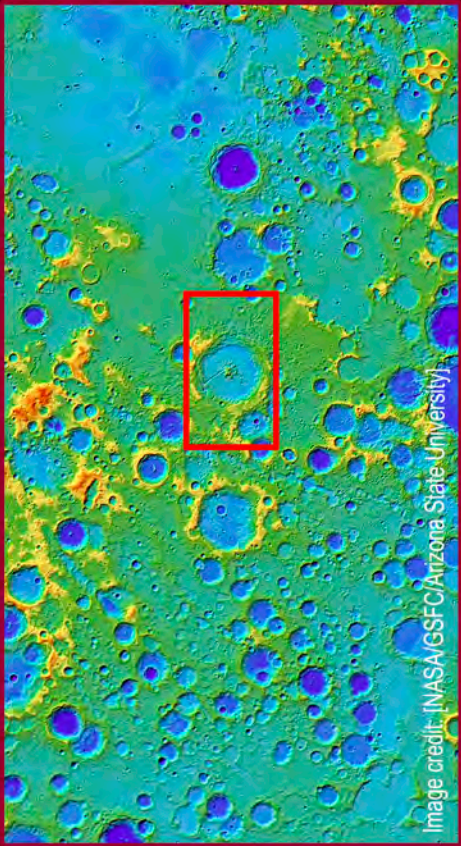


Image credit: [NASA/GSFC/Arizona State University]

CONTEXT IMAGE

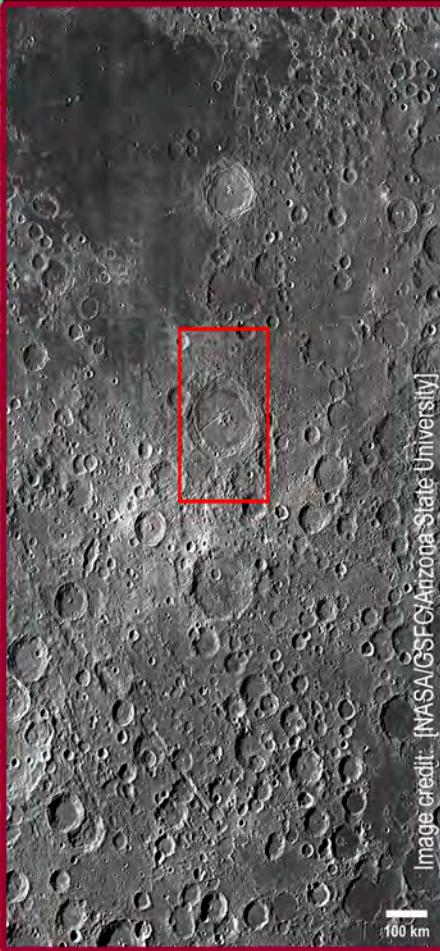


Image credit: [NASA/GSFC/Arizona State University]

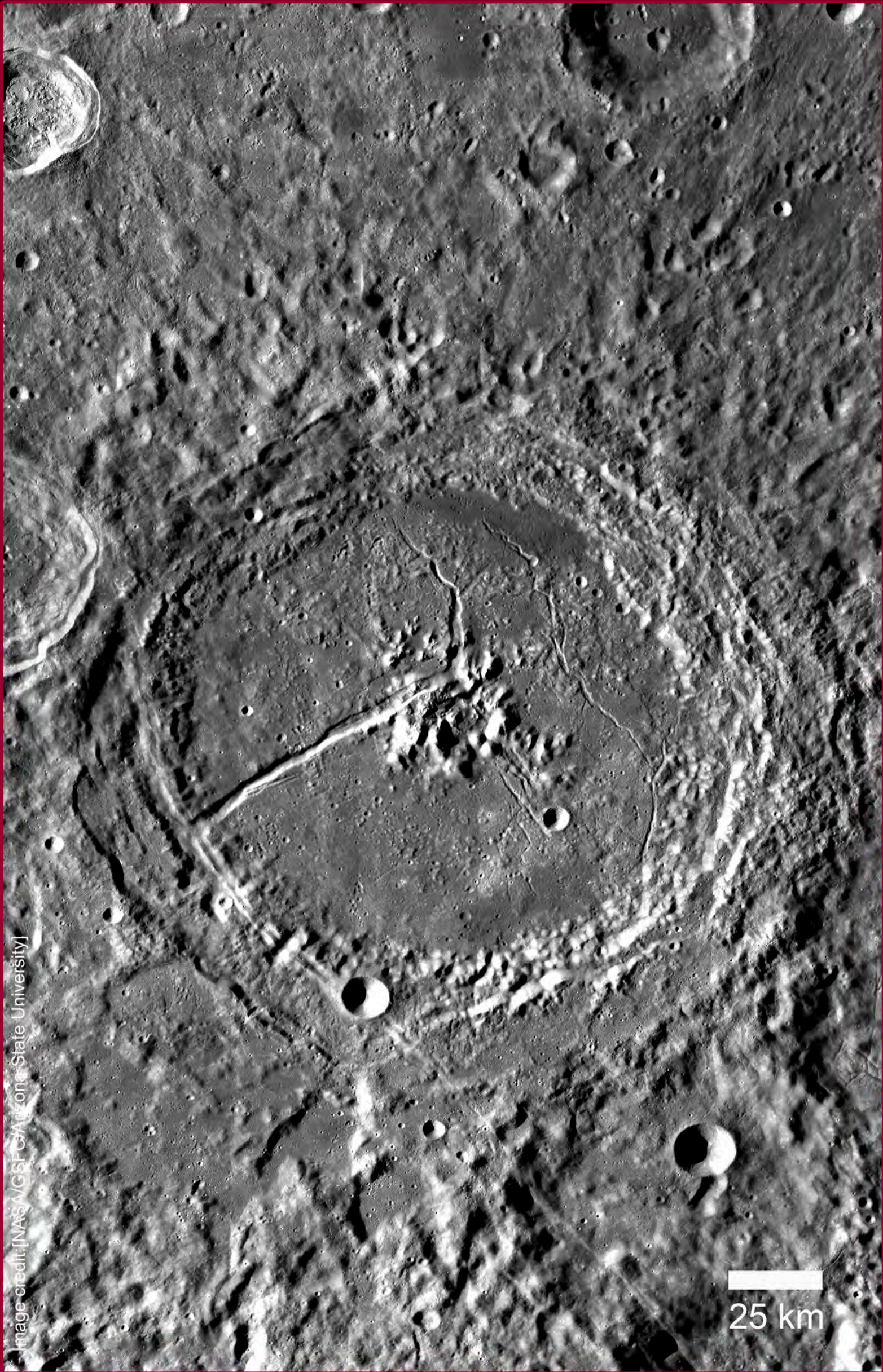


Image credit: [NASA/GSFC/Arizona State University]

25 km

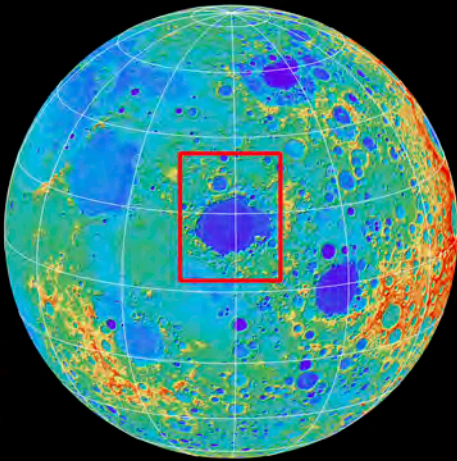




Lunar Image Analysis

Mare Crisium

Lat: 15.50° N
Lon: 58.80° E
Sun angle: Low



WAC ELEVATION

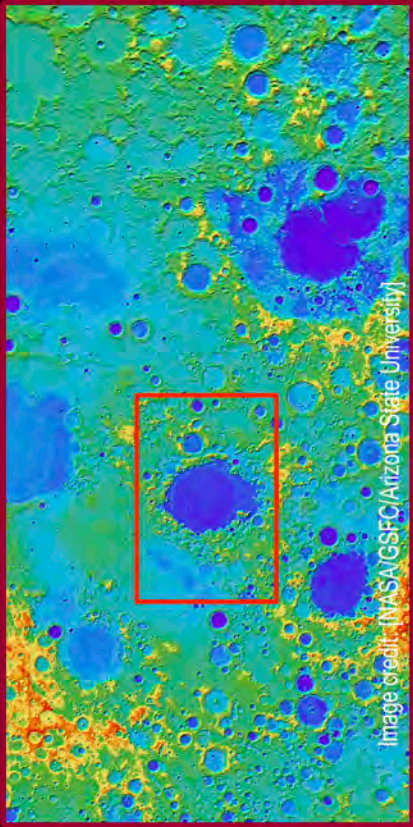


Image credit: [NASA/GSFC/Arizona State University]

CONTEXT IMAGE



Image credit: [NASA/GSFC/Arizona State University]

Image credit: [NASA/GSFC/Arizona State University]

75 km

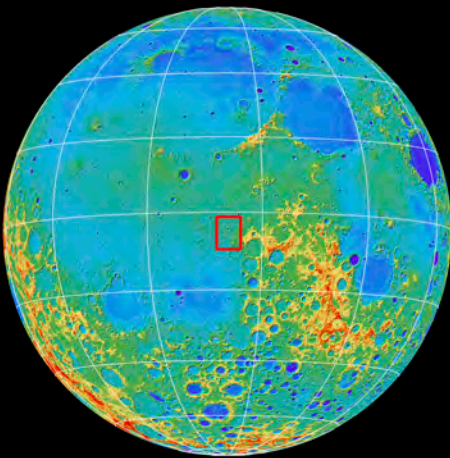




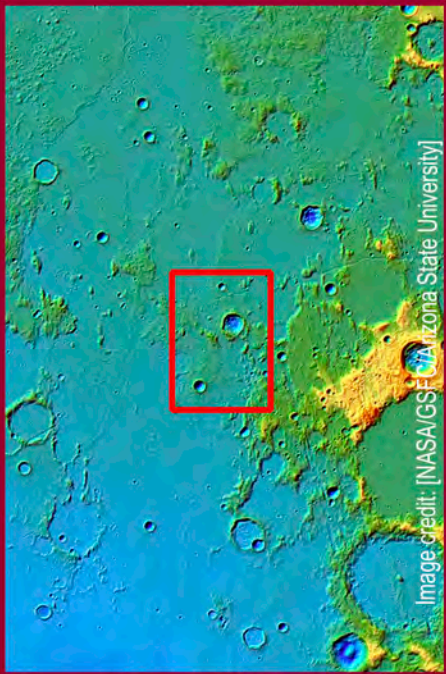
Lunar Image Analysis

Lalande Crater

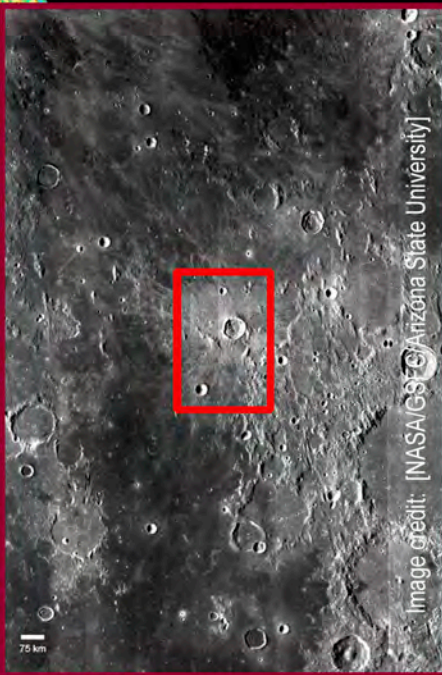
Lat: -4.49°
Lon: 351.34° E
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

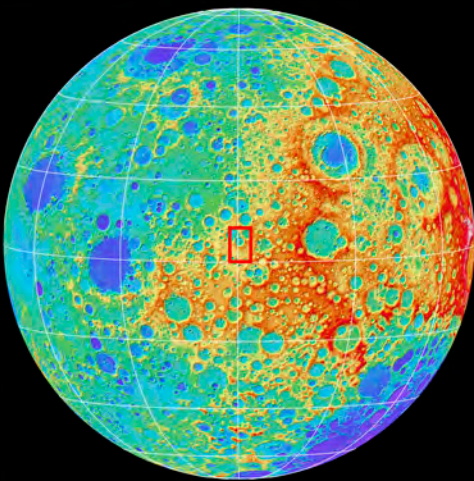




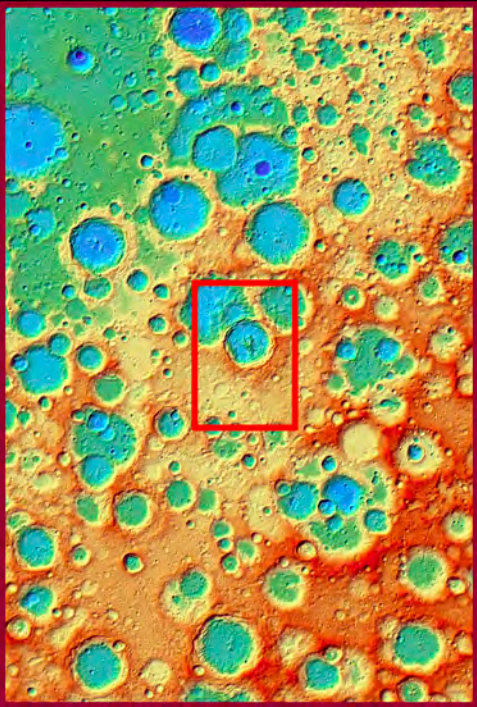
Lunar Image Analysis

King Crater

Lat: 5.01° N
Lon: 120.60° E
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

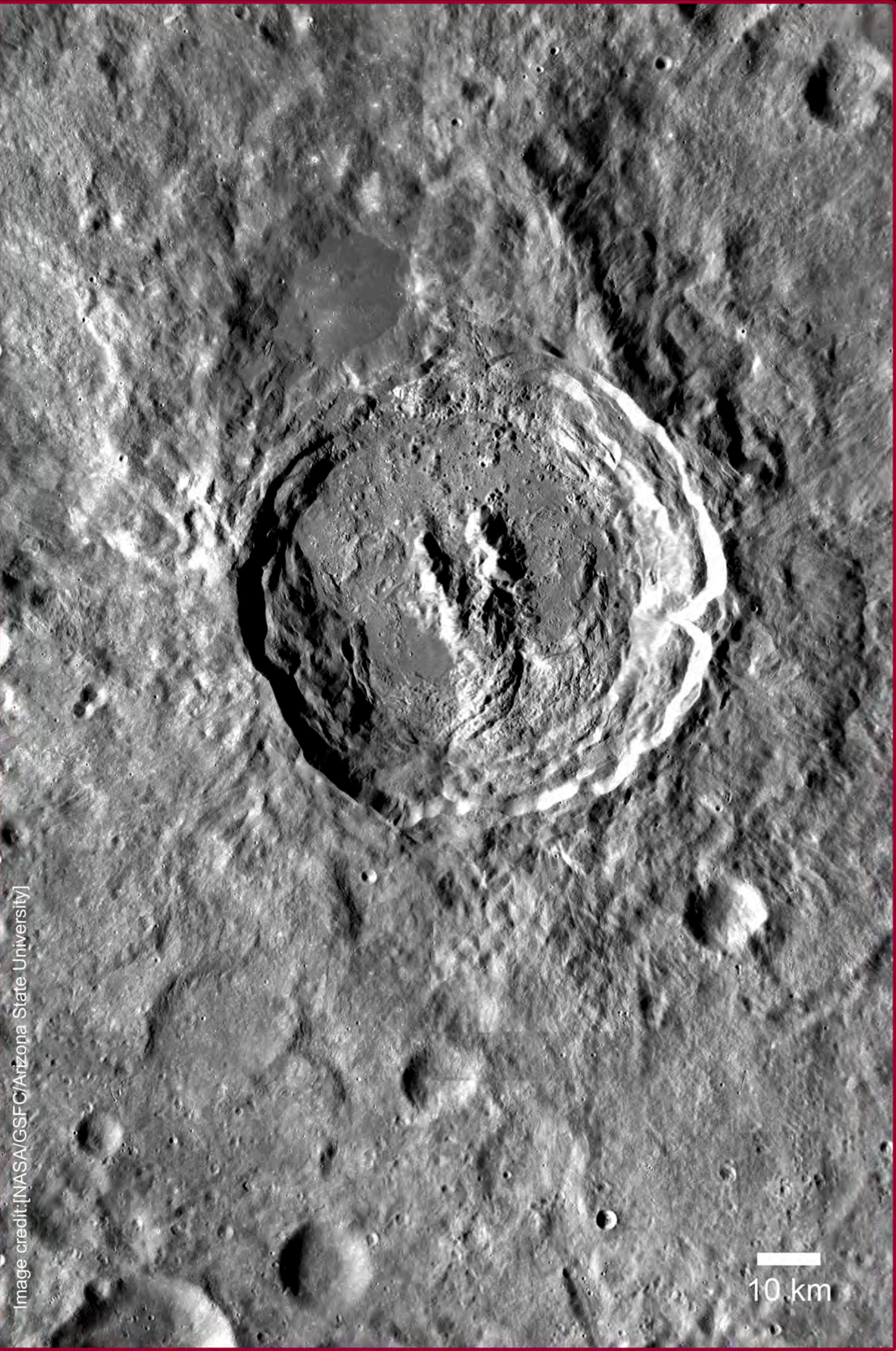
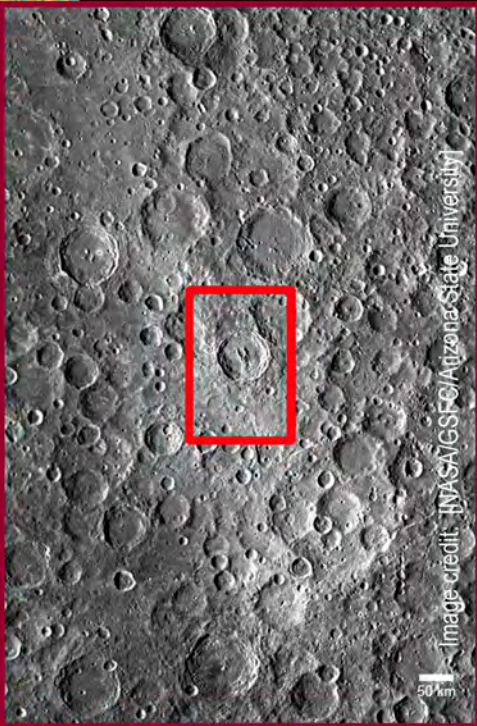


Image credit: [NASA/GSFC/Arizona State University]

Image credit: [NASA/GSFC/Arizona State University]

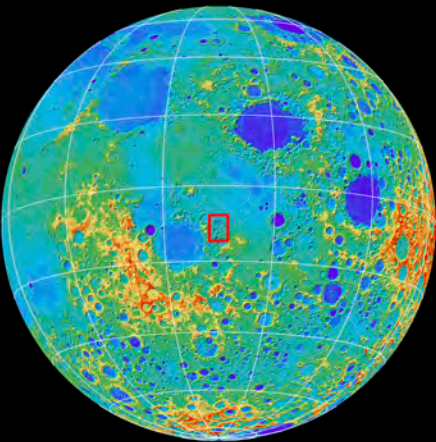




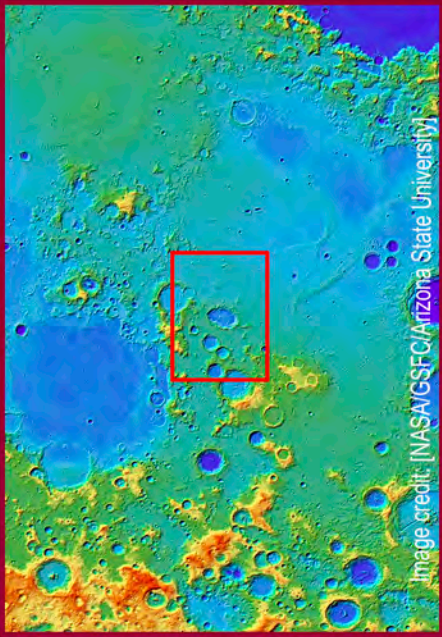
Lunar Image Analysis

Goclenius Crater

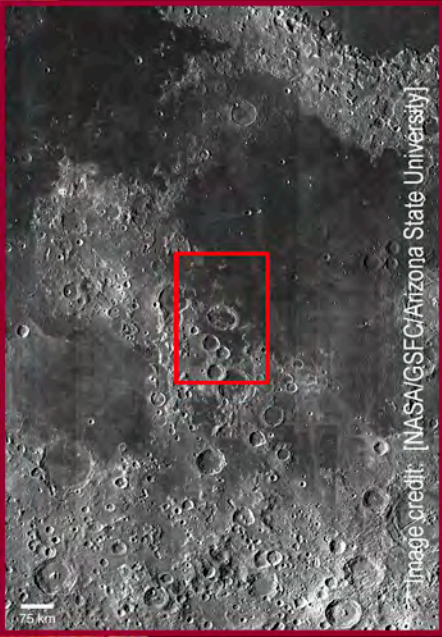
Lat: -10.05° N
Lon: 45.00° E
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

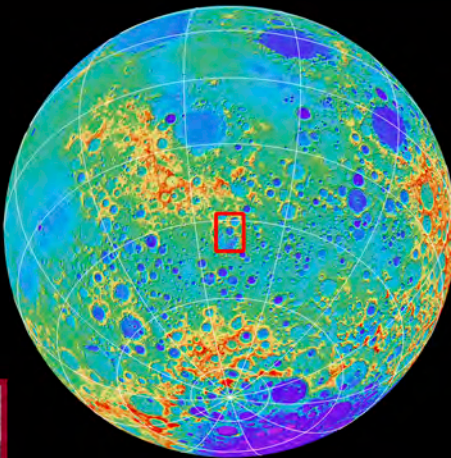




Lunar Image Analysis

Fabricius Crater

Lat: -42.92° N
Lon: 41.95° E
Sun angle: Low



WAC ELEVATION

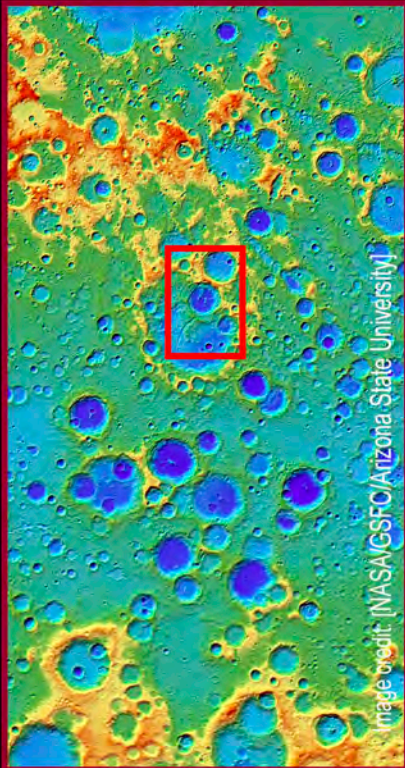


image credit: [NASA/GSFC/Arizona State University]

CONTEXT IMAGE

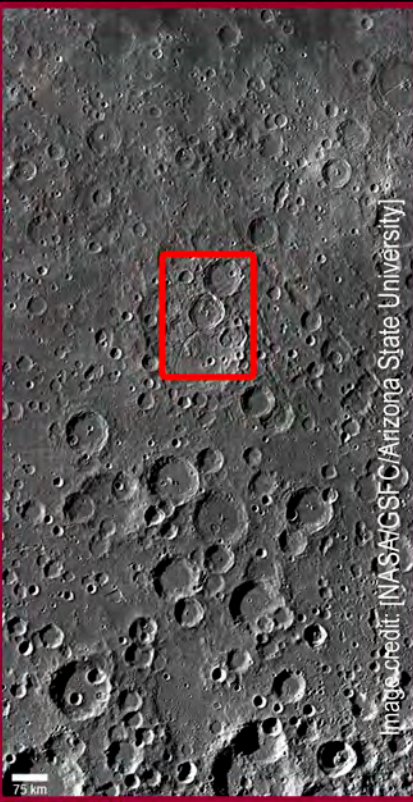


image credit: [NASA/GSFC/Arizona State University]



Image credit: [NASA/GSFC/Arizona State University]

20 km

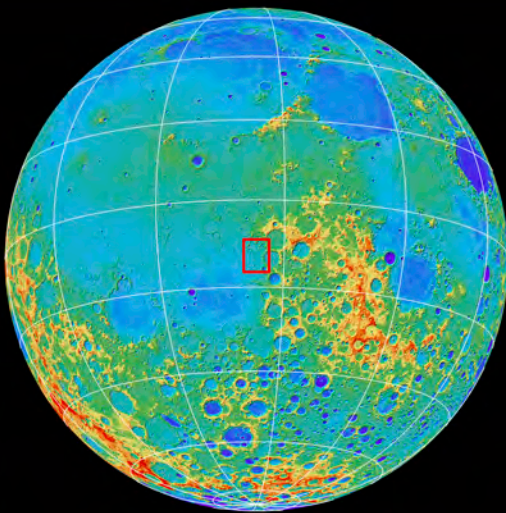




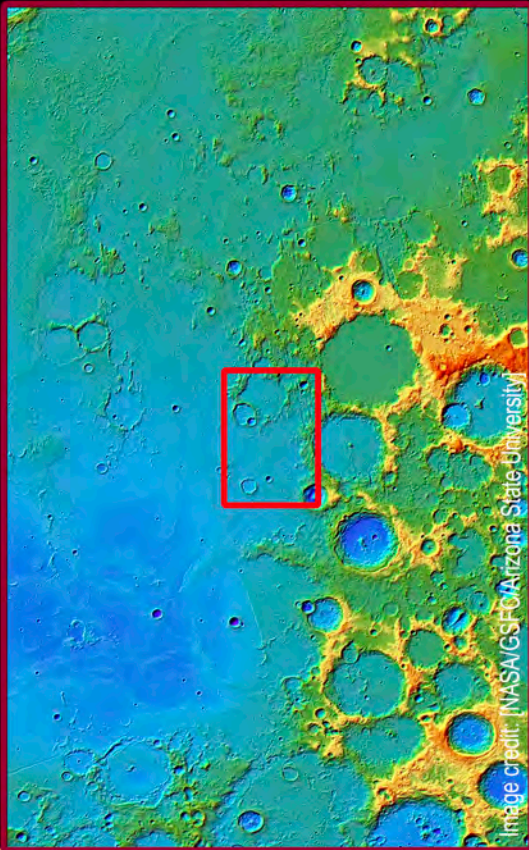
Lunar Image Analysis

Davy Crater

Lat: -11.19° N
Lon: 353.18° E
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

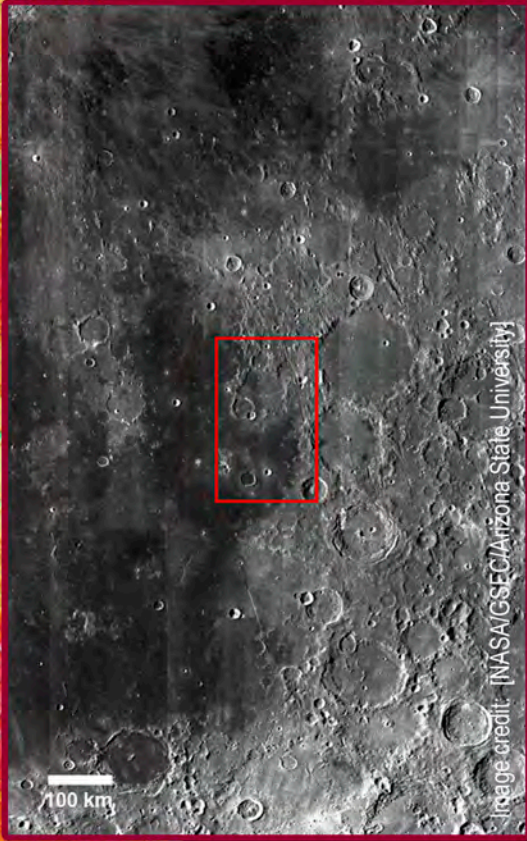


Image credit: [NASA/GSFC/Arizona State University]

Image credit: [NASA/GSFC/Arizona State University]

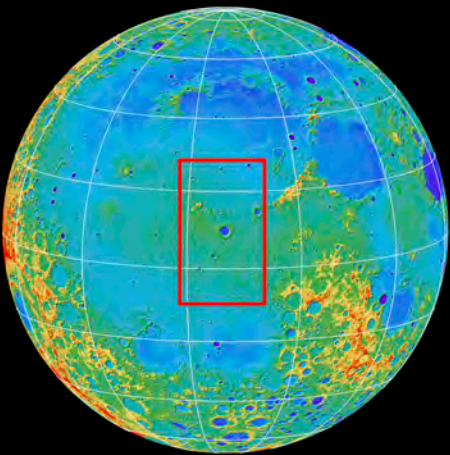




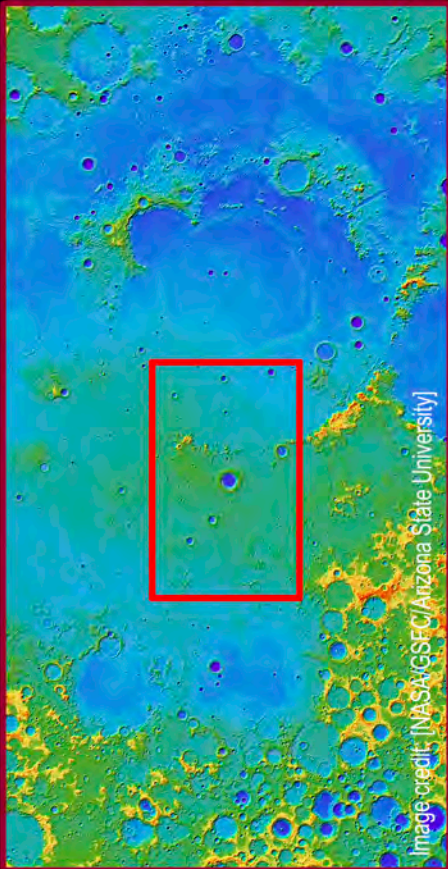
Lunar Image Analysis

Copernicus Crater

Lat: 9.62° N
Lon: 339.89° E
Sun angle: Low



WAC ELEVATION



CONTEXT IMAGE

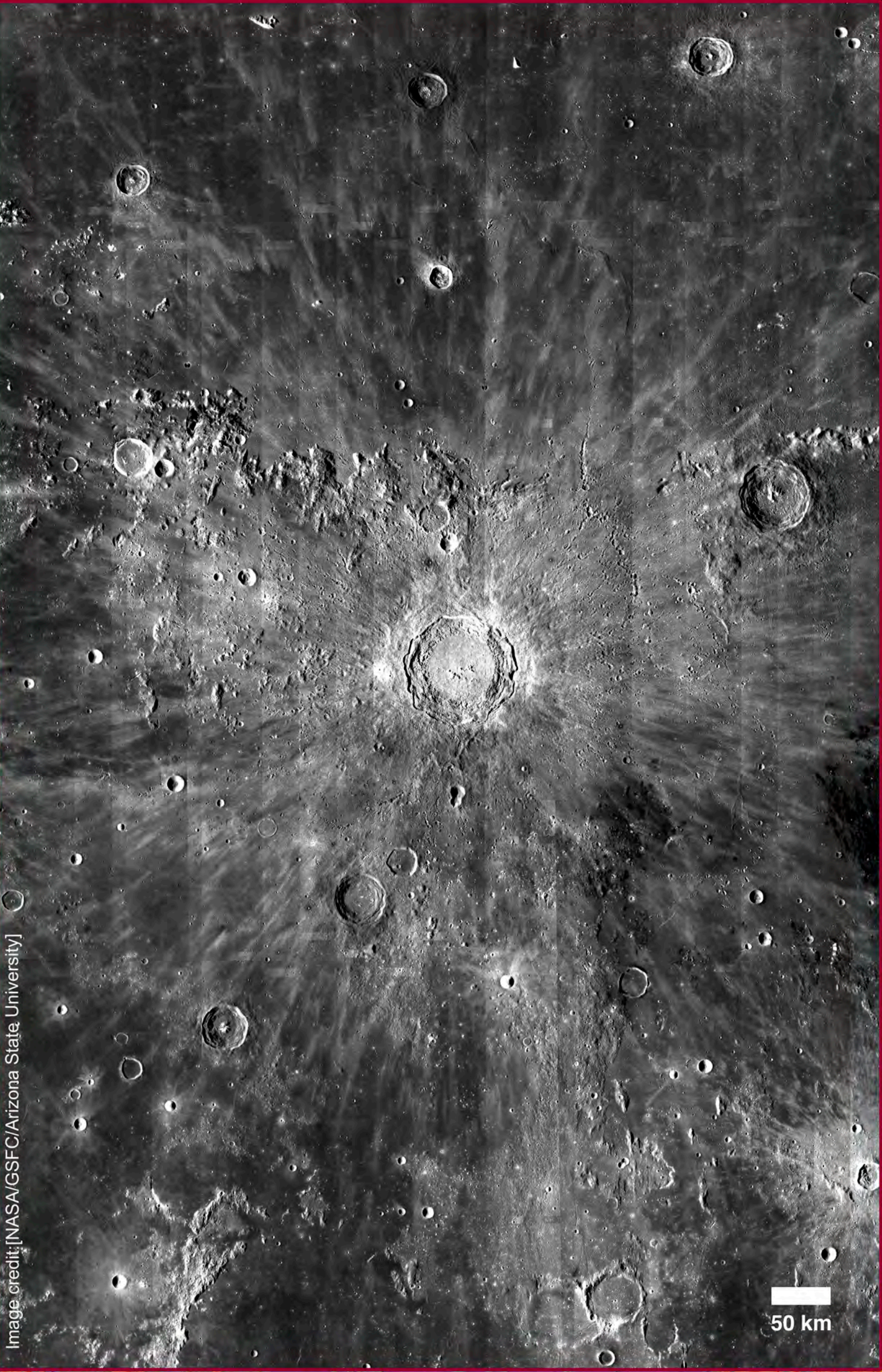
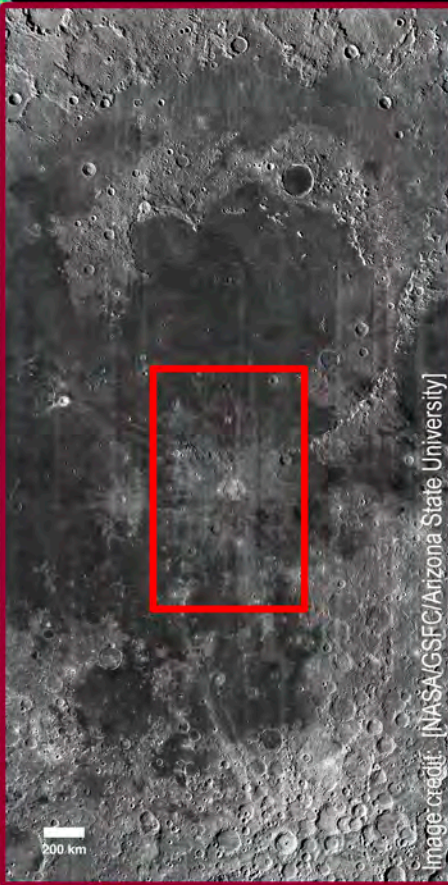


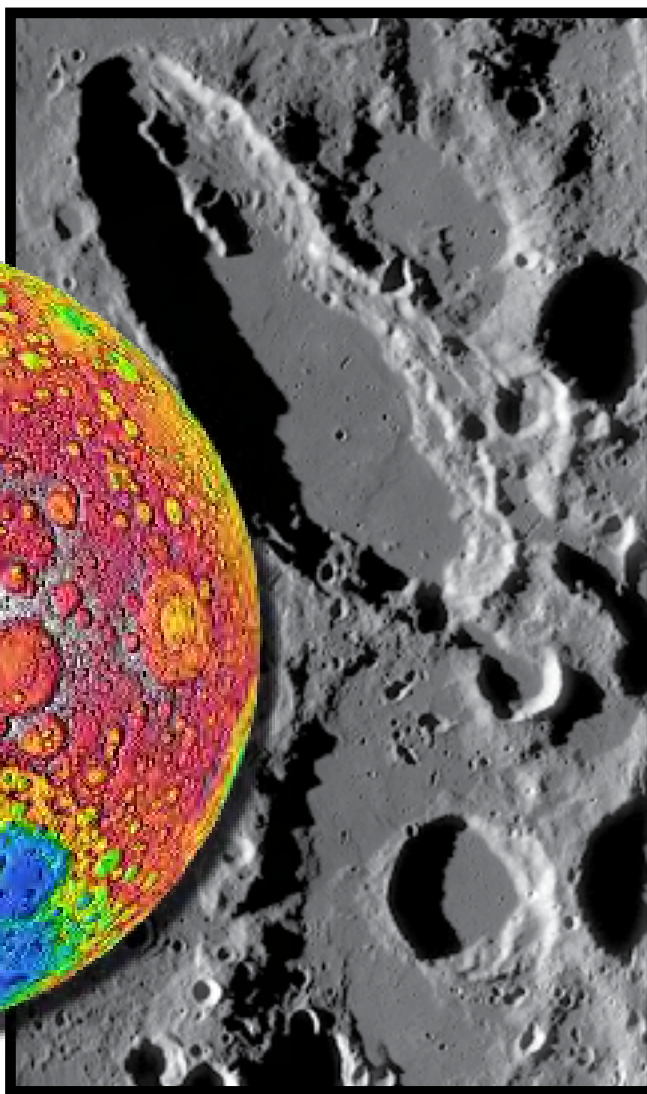
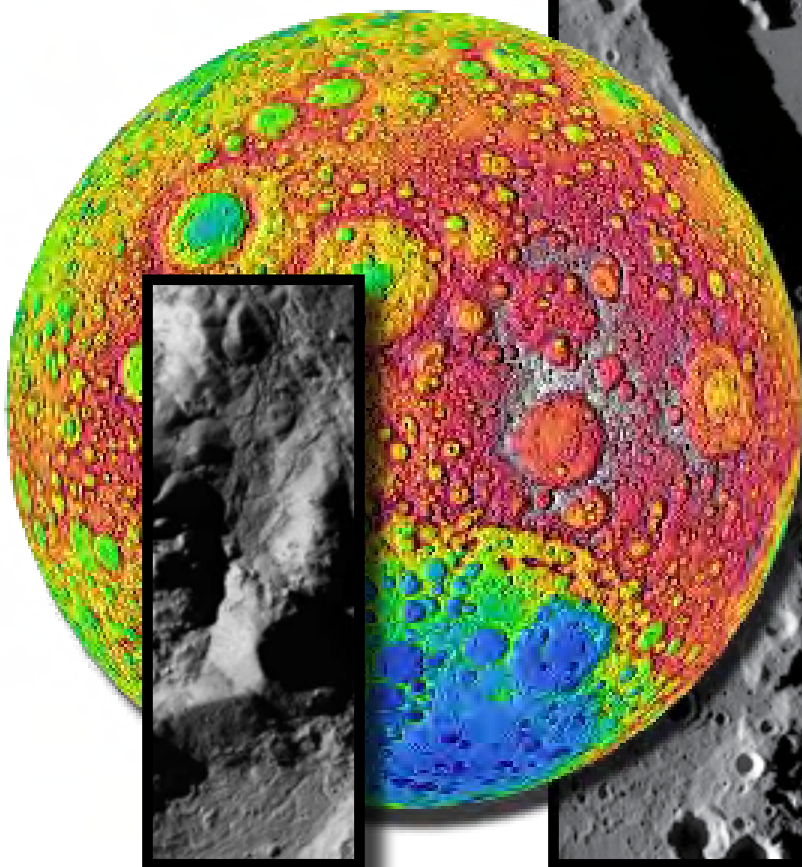
Image credit: [NASA/GSFC/Arizona State University]

50 km





LUNAR FEATURE IDENTIFICATION CHARTS



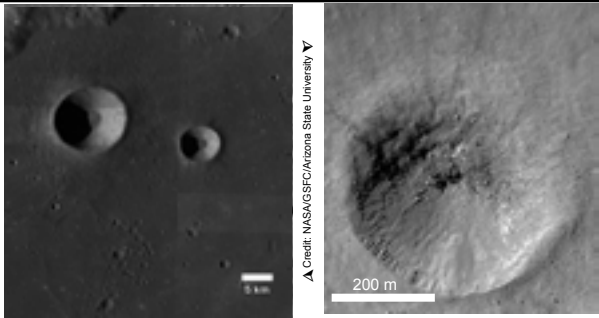
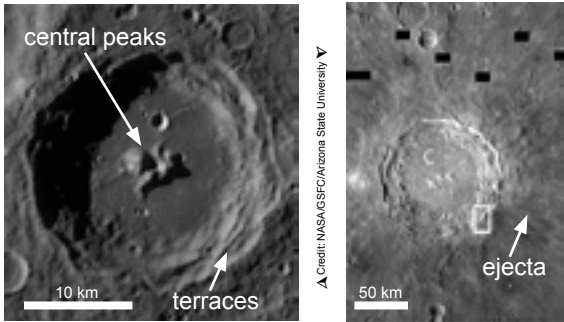
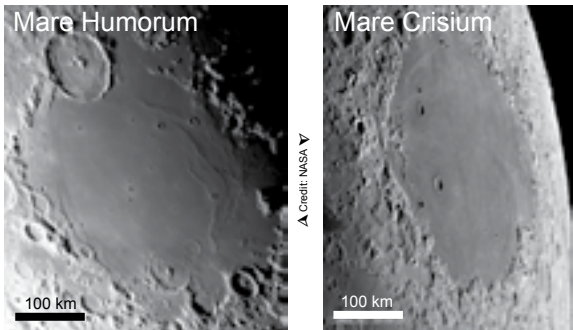
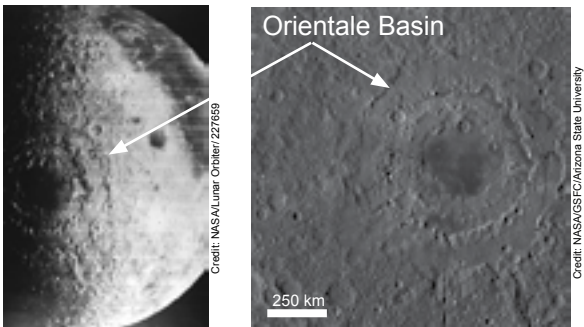
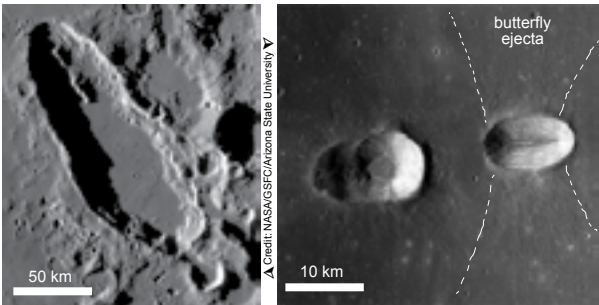
A GUIDE TO THE IDENTIFICATION OF SURFACE FEATURES
ON THE MOON

CHARTS



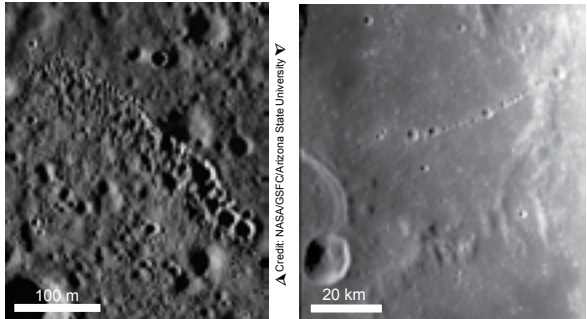
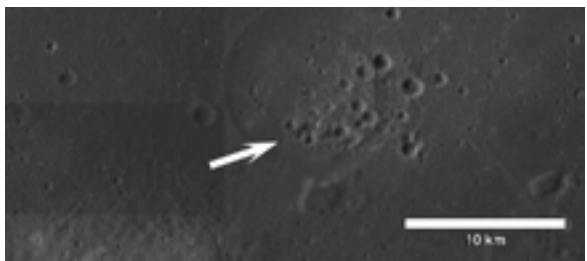
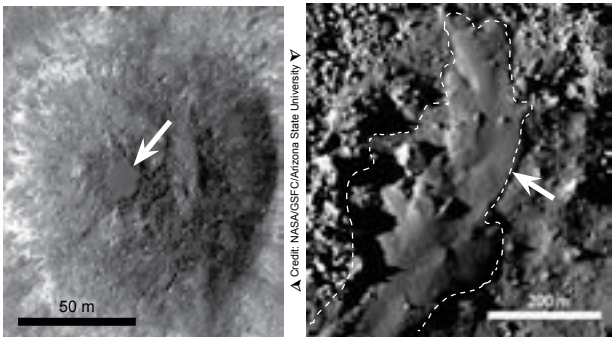
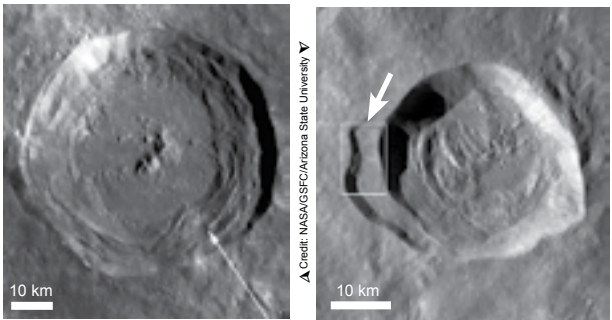
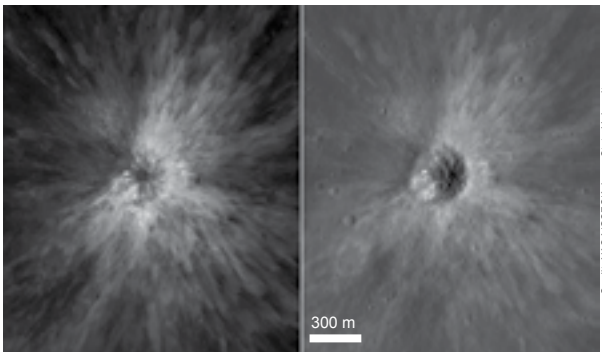
1: LUNAR FEATURE IDENTIFICATION CHART

Primary Craters and Their Features

Feature	Feature Example	Feature Description
Simple Craters	 <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Small bowl-shaped craters • Steep wall and raised rim • Most common type of craters on the Moon • Diameter less than 15 kilometers (10 miles) • Lack a central peak • May have ejecta
Complex Craters	 <p>central peaks</p> <p>terraces</p> <p>ejecta</p> <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Medium to large craters (10-20 km diameter) • Uplifted central peak(s) and flat floor • Many have inward slumping of walls to form terraces • May have ejecta
Impact Basins	 <p>Mare Humorum</p> <p>Mare Crisium</p> <p>Credit: NASA</p>	<ul style="list-style-type: none"> • Largest impact on the Moon • Diameter greater than 300 kilometers • Associated with faulting and deformation • Many are flooded with lava (maria)
Multi-ringed Basins	 <p>Orientale Basin</p> <p>Credit: NASA/Lunar Orbiter 2/27669</p> <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Type of impact basin • Multi-ringed basins formed by the largest lunar impacts • Can have two to four rings • Looks like a target or bull's eye pattern • Formed by asteroid impacts
Irregular Craters	 <p>butterfly ejecta</p> <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Non-circular craters with an oval or irregular shape • Formed by low angle impacts (15° or less) • Often have "butterfly" shaped ejecta pattern

2: LUNAR FEATURE IDENTIFICATION CHART

Secondary Craters and Other Features

Feature		Feature Example	Feature Description
Secondary Craters	Crater Chains	 <p><small>▲ Credit: NASA/GSFC/Arizona State University ▼</small></p>	<ul style="list-style-type: none"> Small secondary impact craters arranged in chains near larger craters Produced by the impact of ejecta from a larger impact Less than 1 km in diameter
	Crater Clusters		<ul style="list-style-type: none"> Small secondary impact craters in clusters formed by the impact of ejecta from larger impacts These craters can be found in areas around larger craters
Impact Melt		 <p><small>▲ Credit: NASA/GSFC/Arizona State University ▼</small></p>	<ul style="list-style-type: none"> Melted rocks and regolith ("soil") that flows like lava and then solidifies Formed from heat generated by impacts Can show flow features Often found at the base of craters where it can "pond" or fill in the floor
Terraces		 <p><small>▲ Credit: NASA/GSFC/Arizona State University ▼</small></p>	<ul style="list-style-type: none"> Terraces form as crater walls slump down onto the crater floor creating a series of flat steps Often have a concentric "stair-step" pattern with circular, nested steps
Ejecta Rays		 <p><small>▲ Credit: NASA/GSFC/Arizona State University ▼</small></p>	<ul style="list-style-type: none"> ejected or "excavated" during an impact Can form radial streaks that look like the spokes of a wheel around a crater Ejecta may be bright or dark depending on composition May indicate direction of impact

3:

LUNAR FEATURE IDENTIFICATION CHART

Volcanic Features

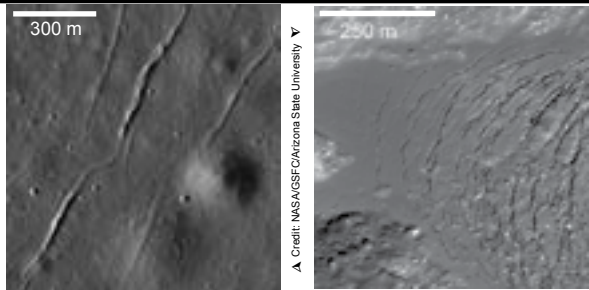
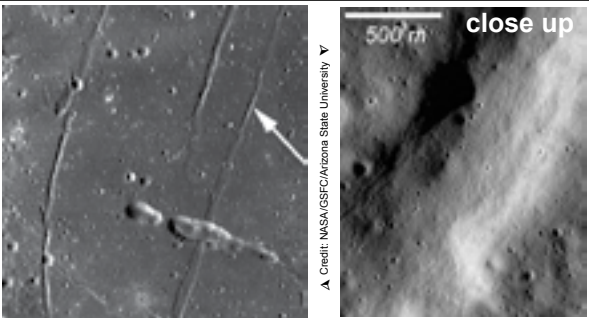
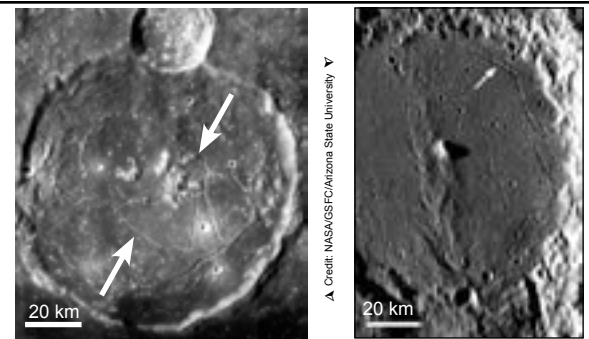
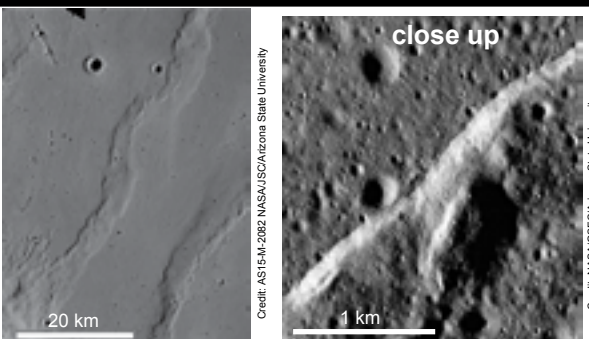
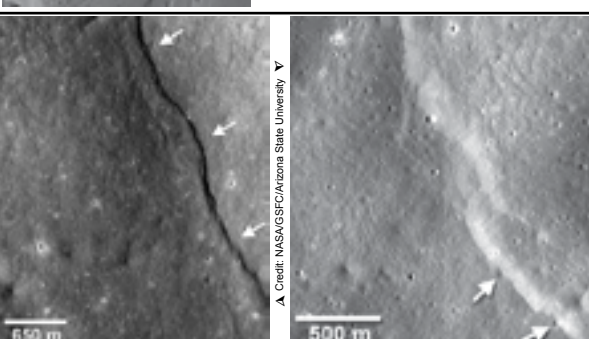


Feature		Feature Example	Feature Description
Maria (Singular: Mare)			<ul style="list-style-type: none"> • Large flows of lava that erupted within and flowed into low-lying impact basins (extremely large craters) • Most occur on the near-side of the Moon (side facing Earth) • Basins are older than the lava filling them • Basalt (lava rock) is darker than the surrounding rock of the highlands and stands out as dark, circular areas
Non-Maria Volcanism	Volcanic Domes		<ul style="list-style-type: none"> • Dome-shaped that may have a central pit crater at the summit (top) • Occur at edges of maria and large craters • Often low relief (height above the surface) and can occur in clusters
	Pyroclastic Vents		<ul style="list-style-type: none"> • Irregular holes that look like craters • Vents may appear to have dark "halos" surrounding them called Dark Mantle Deposits (DMD's) • Small-scale features and hard to identify
	Sinuuous Rilles (Lava Channels)		<ul style="list-style-type: none"> • Long, narrow depressions that look like channels • Have a sinuous path (often with tight curves) • Intersected channels may be large rilles

4: LUNAR FEATURE IDENTIFICATION CHART

Tectonic Features



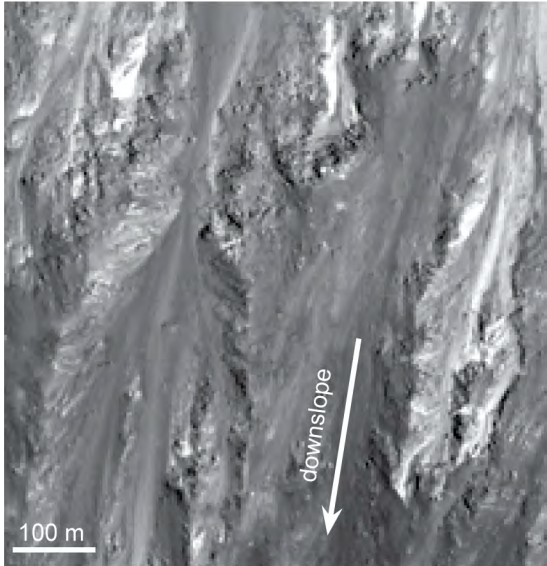
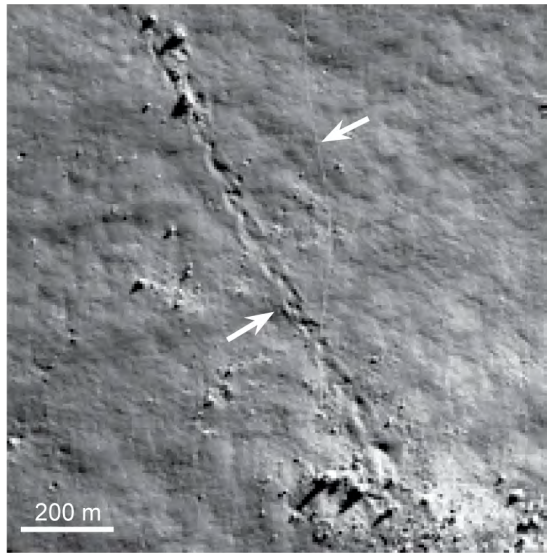
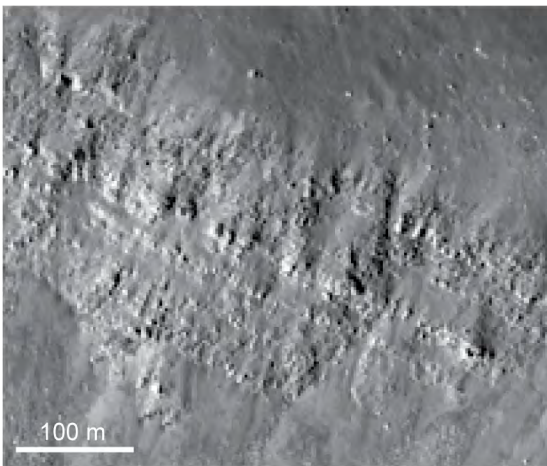
Feature		Feature Example	Feature Description
Tensional Features	Fractures		<ul style="list-style-type: none"> Cracks in areas where the crust has been pulled apart Can be linear (straight) or curved Usually occur in groups Often found in impact melt in the bottom of craters
	Graben		<ul style="list-style-type: none"> A block of land on either side (see diagram at top) Forms a valley with steep scarps and a flat floor Often are very linear straight and long
	Crater Floor Fractures		<ul style="list-style-type: none"> Fractures or cracks on volcanic craters Found in the floors of large to medium sized craters
Comtractional Features	Wrinkle Ridges		<ul style="list-style-type: none"> Irregular features that display positive relief (rise above the surface) Main ridge normally has many smaller wrinkles on top Often found in areas of thick lava flows (maria)
	Lobate Scarps		<ul style="list-style-type: none"> Irregular cliffs or ridges formed by the thickening of the lunar crust Similar to wrinkle ridges, but found in the more rugged highland areas

5:

LUNAR FEATURE IDENTIFICATION CHART

Mass Wasting Features and Layers



Feature	Feature Example	Feature Description
Debris Flow	 <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Loose rocks that have slid down a steep slope • Material often piles up at the bottom of a slope like at the base of a crater wall • May be caused by a nearby impact shaking rocks loose • The flows may have lobes that are tongue or finger shaped • Small-scale features only visible in NAC images
Boulder Trails	 <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Linear features (trails) formed by boulders that have rolled down slope • Some trails are smooth and others are bumpy depending on the shape of the boulder and surface material • Often found in areas near central peaks inside large craters • Small-scale features only visible in NAC images
Layers	 <p>Credit: NASA/GSFC/Arizona State University</p>	<ul style="list-style-type: none"> • Layers may be seen in the walls and central peaks of craters • Layers build up over time and show a history of lava flows • Layer thickness can give information about the eruption that formed the flow • Small-scale features only visible in NAC images

Extension Activities:

PARTICIPATING IN THE LUNAR STUDENT IMAGING PROJECT:

This activity can be used as an introduction to participation in the Lunar Student Imaging Project (LSIP). The Lunar Student Imaging Project allows students to conduct research about the Moon using the LROC-WAC visible images from the Lunar Reconnaissance Orbiter spacecraft.

RESEARCH DESIGN

Students will have the opportunity to design a research project using a provided question with the LROC-WAC Equatorial Mosaic images.

DATA ANALYSIS

Students will have the opportunity to collect data and graph the data using a provided question with the LROC WAC Equatorial Mosaic images.

RESEARCH DESIGN AND DATA ANALYSIS

Students will have the opportunity to design a research project, collect data, and graph the data using a provided question with the LROC-WAC Equatorial Mosaic images.